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SUBLITTORAL GAMMARIDEAN AMPHIPODS OF SOFT SEDIMENTS IN THE BAY OF FUNDY

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Two benthic sampling designs were used to collect gammaridean amphipods of soft sediments in the Bay of Fundy for taxonomic analysis. The first was a survey consisting of two grab samples at 266 stations spread throughout the Bay to determine geographic distribution. The second involved intensive sampling at two stations to determine seasonal changes in species richness, density, and biomass.

Ninety-nine amphipod species were found. Two species were new to science and 6 are additions to the Canadian Atlantic fauna. Certain amphipods were limited to 1 or 2 of the 3 major surficial sediment types in the Bay, while other species were found on all sediment types. Seasonal sampling over a 2-yr period showed that gammaridean amphipod species richness was less, individual density and biomass were greater, at a shallow estuarine location compared to a deep (80 m) location. Two of the 3 dominant gammarideans at the shallow location were only temporary occupants. The deep location had 6 dominant species which were present throughout the 2-yr sampling period, although changes in subdominant species and densities suggested the occurrence of a perturbing event of unknown nature.

Deux approches furent utilisées pour échantillonner les amphipodes gammarides des sédiments mous de la baie de Fundy afin de les soumettre à une analyse taxonomique. Dans un premier temps, la distribution géographique de ces crustacés fut déterminée à partir de deux échantillons prélevés à la benne a 266 stations couvrant la baie de Fundy. Dans un deuxième temps, les variations saissonnières de la diversité, de la densité et de la biomasse specifiques furent étudiées à partir de deux stations échantillonnées intensivement.

Quatre-vingt-dix-neuf espèces d'amphipodes furent trouvées. Deux de ces espèces sont nouvelles et représentent des additions à la faune atlantique canadienne. Certaines espèces d'amphipodes se limitaient à 1 ou 2 des 3 types principaux de sédiments superficiels de la boie, alors que d'autres espèces furent trouveés dans tous les types de sédiments. L'echantillonnage saisonnier s'echelonnant sur une période de deux ans a montré que la diversité des espèces d'amphipodes gammarides était plus réduite, la densité des individus et la biomasse étaieut plus élelées à une station estuarienne située en eau peu profonde comparée a une station située en eau profonde (80 m). Deux des troix espèces dominantes à la station située en eau peu profonde furent des occupants temporaires. A la station située en eau plus profonde, 6 espèces furent dominantes et elles furent présents pendant les deux années de la période d'echantillonnage. Des changements dans les espèces sous-dominantes et dans les densités ont suggéré qu'un événement perturbateur de nature indéterminé s'est produit à cette station.

Introduction

The taxonomy of Gammaridea (Crustacea, Amphipoda) from the littoral and shallow sublittoral regions of the Bay of Fundy is well known (Bousfield 1973). The taxonomy of sublittoral gammarideans was relatively little known (see Shoemaker 1930, 1931) until recently when systematic sublittoral sampling in the Bay of Fundy was undertaken (Peer *et al.* 1980; Wildish *et al.* 1983). Sampling for this project at depths to 220 m, revealed species of Gammaridea new to science such as *Haploops fundiensis* (Wildish & Dickinson 1982) and *Melita* n. sp. (Brunel & Dadswell in preparation) and 6 new additions of species to the Canadian Atlantic fauna.

The original purpose of the 1978-79 sampling was to make an estimate of production of all abundant macrofauna in the upper and lower parts of the Bay (see Wildish & Peer 1983). In addition, a shallow and a deep benthic location were studied in detail during 1978-80 to determine the productivity of the most abundant species present. However, only a few species could be treated in detail and gammaridean amphipods were chosen for two reasons. Firstly, marine infaunal amphipods are among the least studied in terms of production estimation (Wildish & Peer 1981) and secondly, these amphipods are important as food for groundfish in the Bay of Fundy (Tyler 1972).

Presented here is an overview of the distributional ecology and taxonomy of the known sublittoral gammarideans in the Bay of Fundy. Included are data from earlier work in some of its estuaries (Wildish 1983), geographic sampling and time-series data obtained from a shallow and deep location in the Bay of Fundy. The taxonomic list has been made as complete as possible by including gammarideans removed from stomachs of bottom feeding fish such as cod, haddock and flounder collected by others at the Biological Station, St. Andrews.

Materials and Methods

Soft-sediment macrofauna were sampled with one of the following grabs: Smith-McIntyre, modified Van Veen or Hunter-Simpson (Hunter & Simpson 1976). Each grab had a sampling surface area of 0.1 m^2 and quantitative samples contained 10-16 L of sediment slurry. Sediment was sieved on deck with running sea water through mesh sizes of 2.5 and 0.8 mm. The 0.8 mm mesh was found to be inefficient in retaining some Gammaridea smaller than 3-4 mm body length. All animals retained on the sieves were preserved in 5% formalin in sea water in tightly sealed plastic buckets.

In the laboratory, Gammaridea were separated from other animals, sorted to species and preserved in 70% ethanol. Bulk weighings were made of the most abundant species; their wet weights are ethanol-preserved weights correct to 0.1 mg.

In the geographical sampling survey, duplicate grab samples were combined giving a total surface area sampled of 0.2 m^2. Positions of the 266 stations sampled are indicated in Fig 1. Only quantitative samples, that is, those containing 10-16 L of sediment were used in the present analysis to determine density and biomass.

Two sampling stations were chosen for detailed seasonal time-series investigations. These were Digdeguash estuary station 32 (1977-1978) and station 82 (1979-1980) off the Wolves Islands in the western mouth of the Bay of Fundy. Seasonal samples consisted of 5-30 individual grabs per sampling date, each of which was sorted separately. Sampling was conducted for 2 years at approximately 2-month intervals.

The general location of the sampling sites is shown in Fig 1. Descriptions of three surficial sediment types by Fader *et al.* (1977) for the lower Bay of Fundy have been used in this paper. La Have clay refers to a net depositional silt/clay sediment, Scotian Shelf drift is a glacial till consisting of poorly sorted sediments of all sizes, and Sambro sand is a sediment undergoing reworking with characteristic fields of sand waves and ripple marks (Fader *et al.* 1977).

Results

Geographic Survey

A summary of the sampling effort and numbers of species found in each region of the Bay of Fundy is shown in Table I.

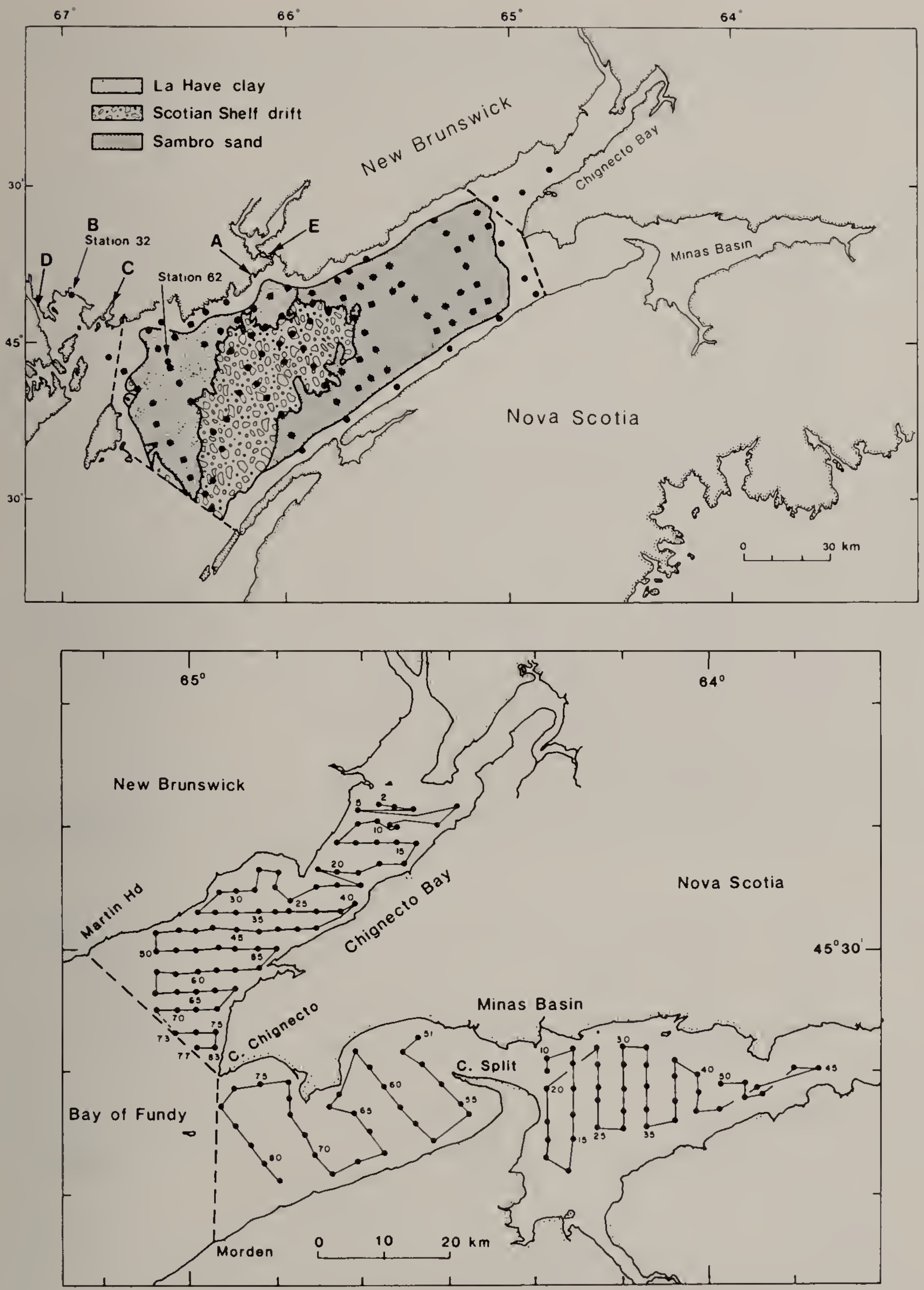

Fig 1 A. Map of the lower Bay of Fundy showing sampling limits at the mouth of the Bay, geographic sampling locations, the two temporal sampling locations by station number, the surficial sediment distribution after Fader *et al*. (1977) and the position of five estuaries designated by letter as in Table II.

B. Map of the upper Bay of Fundy showing sampling limits and sampling locations.

Table I Numbers of individual Gammaridea, sampling effort, and numbers of species in soft sediments of the Bay of Fundy. *0.1 m^2 replicates.

Area	Region	Total number of individuals (N)	Number of quantitative 0.2 m replicates (X)	Total species number (S)	Potential sampling area KM^2	S/X	N/S
Upper Bay	Chignecto Bay	851	37*	24	1099	0.6	35.5
	Minas Basin	297	22*	13	2010	0.6	22.8
Lower Bay	LaHave clay	144	18	18	2186	1.0	8.0
	Scotian Shelf	274	17	17	2251	1.0	16.1
	Sambro sand	115	24	16	4183	0.7	7.2
N.B. estuaries	Musquash	14	9	4	12	0.4	3.5
	Digdeguash	17	1	3	6	3.0	5.7
	L'Etang	1631	4	15	24	3.8	108.7
	St. Croix	12	7	6	16	0.9	2.0
	Saint John Harbour	420	11	2	28	0.2	210.0

Cumulative species/area curves were plotted and representative data are shown in Fig 2, and 3. Of interest is the "species discovery rate," illustrated by these curves, which may be either an arithmetic (Fig 2) or logarithmic (Fig 3) function of area.

Numbers of individuals per species, N/S, are notably high in L'Etang and Saint John Harbour (Table I). In lower L'Etang, organic enrichment caused by pulpmill pollution (Wildish 1982) is the probable reason. Similarly, pollution inclusive of pulpmills and municipal sewage is responsible for organic enrichment in Saint John Harbour. Only *Gammarus oceanicus* mixed with a small proportion of *G. setosus* is present in the Harbour, occurring in large numbers between the interstices of waste wood bark (Wildish 1982).

Average densities of gammarideans based on the total number of stations occupied are shown in Tables II to IV. Densities of species such as *Leptocheirus pinguis* and *G. oceansicus* are high in the estuaries (Table II). Because the grab used

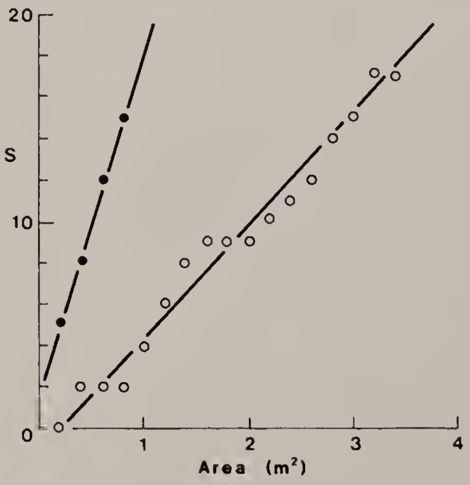

Fig 2 Gammaridean species/area curve for L'Etang Inlet sediments (solid dots) sampled August, 1975 and Scotian Shelf sediment (open dots) within the lower Bay sampled May, 1978.

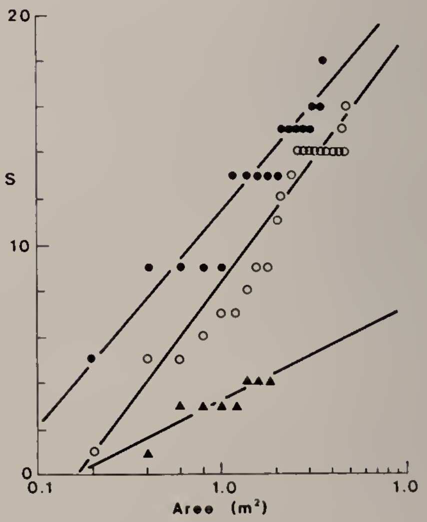

Fig 3 Gammaridean species/area curve for Musquash estuary sampled June, 1973 (solid triangles); La Have clay (solid dots) and Sambro sand sediments (open dots) in the lower Bay sampled May, 1978.

Table II Presence/absence record of Gammaridea in five New Brunswick estuaries. Numbers refer to mean density per m^2 and bracketed figures number of stations averaged.

Taxa	Trophic type	A	B	C	D	E
Ampeliscidae						
Ampelisca abdita	S/D	—	—	93(1)	—	—
A. macrocephalus	S/D	—	—	—	1(1)	—
Phoxocephalidae						
Harpinia propinqua	D	—	—	26(3)	—	—
Melitidae						
Casco bigelowi	D	—	62(1)	—	2(2)	—
Maera danae	D	—	—	3(1)	—	—
Ischyroceridae						
Erichthonius rubricornis	S	—	—	3(1)	—	—
Corophidae						
Corophium volutator		11(4)	—	3(1)	—	—
C. bonelli	*S*	—	—	*20(1)*	—	—
C. crassicorne		—	—	42(2)	—	—
Lysianassidae						
Anonyx liljeborgi	D	—	—	22(2)	—	—
Orchomenella minuta	D	—	—	211(2)	—	—
Oedicerotidae						
Monoculodes edwardsi		—	—	3(1)	—	—
Aoridae						
Leptocheirus pinguis	S/D	6(2)	2(1)	1493(4)	1(3)	—
Unicola irrorata	D	—	—	282(4)	11(1)	—
Pleustidae						
Stenopleustes inermis	D	—	—	3(1)	—	—
Gammaridae						
Gammarus oceanicus		4(2)	—	3(1)	39(1)	588(3)
G. lawrencianus		3(3)	—	—	1(1)	—
G. setosus		—	—	—	—	?
Haustoriidae						
Pontoporeia femorata	D	—	23(1)	—	—	—

Letters: A = Musquash, B = Digdeguash, C = L'Etang, D = St. Croix, and E = Saint John Harbour. Trophic type code, S = suspension feeder, D = deposit feeder.

in this study probably could not quantitatively recover the pieces of wood bark and attached *Gammarus*, the density of *G. oceanicus* in Saint John Harbour (Table II) is probably underestimated. Compared to the lower Bay of Fundy (Table III), estuarine densities of gammarideans are higher. The two commonest species in the Bay of Fundy, judged by the number of stations at which they occur, are *H. fundiensis* and *L. pinguis* (Table IV). Average densities for the former of $42/m^2$ and latter of $35/m^2$ are less than for the most common estuarine species. Density of upper Bay of Fundy gammarideans was generally lower than those of the lower Bay.

Table III Most abundant Gammaridea in the lower Bay of Fundy showing trophic type, mean density and biomass, and number of stations at which the species was found (N). Species grouped by surficial sediment preference as given by Fader, *et al.* (1977).

Species	Trophic type	No./m²	g/m²	N
Sambro sand only				
Anonyx sarsi	D/O	5	0.015	4
Psammonyx nobilis	D	5	0.204	4
Podoceropsis nitida	D	12	0.075	3
Gammaropsis melanops	D	5	0.050	6
Pleusymtes glaber	D	5	0.023	3
Scotian Shelf and LaHave clay				
Byblis gaimardi	S/D	6	0.036	5
Haploops setosa	S/D	78	0.761	8
Haploops fundiensis	S/D	42	0.164	24
Dyopedos monacanthus	S	10	0.065	6
Scotian Shelf and Sambro sand				
Corophium bonelli	S	8	0.072	4
Erichthonius difformis	S	13	0.033	4
Dyopedos porrectus	S	9	0.072	4
Present on all sediment types				
Unciola irrorata	D	17	0.116	16
Unciola leucopis	D	17	0.121	15
Protomedia fasciata	D	17	0.088	7
Phoxocephalus holbolli	D	9	0.055	7
Harpinia propinqua	D	7	0.037	11
Leptocheirus pinquis	S/D	35	0.583	21
Casco bigelowi	D	8	0.171	8
Erichthonius rubricornis	S	10	0.064	5

Trophic type code as in Table II plus O = omnivorous scavenger.

Seasonal Sampling

The physical characteristics of the two intensively sampled stations are given in Table V. Sampling at Station No. 82 indicates that a number of grab replicates must be taken before the species/area curve becomes asymptotic (Fig 4). Thus, stations represented by two grab replicates during geographic sampling are underestimates of the total number of species present.

The most noticeable difference between the shallow estuarine location (Table VI) and the 80 m deep one in the lower Bay of Fundy (Table VII) was the fewer species: only 8 at the former compared to 26 species at the latter, despite comparable sampling efforts. Further analysis of the shallow location (Wildish, 1980a, Table II) indicated that, although *Casco bigelowi* was present on all sampling occasions, the probability of finding it with 15-29 replicates varied from 0.15 to 1.00. The other two dominants, *Leptocheirus pinguis* and *Pontoporeia femorata*, were totally absent for some months, indicating that these species had not permanently established themselves or their life cycles precluded collection (Wildish 1980a). Depopulation probably occurs as a result of wave activity following storms, causing washout of the animals (Wildish & Kristmanson 1980).

Table IV Most abundant Gammaridea in the upper Bay of Fundy showing trophic type, mean density, biomass and number of stations at which the species was found (N). Trophic types as in Table II.

Taxa	Trophic type	Chignecto Bay			Minas Basin		
		No./m^2	G/m^2	N	No./m^2	g/m^2	N
Ampeliscidae							
Haploops fundiensis	S/D	3	0.015	13			
Ampelisca macrocephala	S/D	1	—	1			
Ampelisca vadorum	S/D	1	0.006	7	11	0.016	4
Isaeidae							
Podoceropsis nitida		2	—	1			
Photis pollex	S	1	—	3			
Protomedia fasciata	D	5	0.003	6			
Phoxocephalidae							
Harpinia crenulata	D	1	—	1			
H. propinqua	D	3	0.002	4			
Phoxocephalus holbolli	D	2	0.004	10	7	0.011	5
Melitidae							
Casco bigelowi	D	2	0.084	11			
Melita dentata	D	1	—	2	3	0.047	3
Melita n.sp.	D	1	0.022	3			
Maera danae	D	3	0.022	6	2	0.010	3
Ischyroceridae							
Ischyrocerus megacheir	S	2	—	5			
I. anguipes	S				1	0.004	4
Jassa falcata	S				7	0.003	1
Erichthonius difformis	S				1	0.006	1
E. rubricornis	S	6	0.002	5			
Corophidae							
Corophium bonelli	S				8	0.001	8
C. acherusicum		64	0.129	2			
C. crassicorne					1	—	1
Podoceridae							
Dyopedos monacanthus	S	1	—				
Aoridae							
Leptocheirus pinguis	S/D	9	0.118	18	5	0.044	5
Unciola irrorata	D	14	0.037	25	7	0.023	13
U. leucopis	D	1	—	4			
Lysianassidae							
Tmetonyx cicada		1	0.020	1			
Stenothoidae							
Metopa alderi		1	—	—			
Pleustidae							
Stenopleustes gracilis	D	1	0.001	1	2	0.002	2
Pleusymtes glaber	D				4	0.004	2
Pontogeneiidae							
Pontogeneia inermis					1	0.001	1

Table V Physical characteristics of the two seasonal sampling stations.

Parameter	Digdeguash estuary Shallow station No. 32	Bay of Fundy Deep station No. 82
Position	45°09.3′N, 66°57.5′W	44°55.7′N, 66°32.5′W
Depth, m at LW and HW	4-12	73-80
Temperature, °C:		
Seasonal range	−1.8-18.0	2.1-11.0
Tidal range, m	8.0	7.0
Salinity, o/oo	25-31	30-32
Tidal currents, cm/s	9.3 (max. 47.9)	20.5 (max. 39.6)
Max. wave height, m (direction in brackets)	1.0 (SSE)	12.2 (SSW)
Mean ATP bottom water, μg/L	324	98

A single "depopulation" event possibly occurred during the 2-year sampling program at Station 82 as suggested by the species area curve (Fig 4). The first asymptotic level, reached after 4-8 m^2 sampling, is 15-16 species. Following depopulation (in January 1980), both amphipod density and species richness showed a marked rise without indication, in the case of the latter, of asymptotic levelling off. The new equilibrium diversity may exceed 26 species (Fig 4). The cause for this change in species richness and density is unknown, but does not appear to be related to a change in sampling procedure. A more detailed seasonal investigation

Table VI Density and biomass of Gammaridea in the Digdeguash estuary sampled during 1977-79. The percentage probability of finding each amphipod is based on its presence/absence in 383 grab replicates.

Taxa	% probability	Trophic group	Density, m^2 mean	Density, m^2 max.	Wet wt, g/m^2 mean	Wet wt, g/m^2 max.
Ampeliscidae						
Ampelisca abdita	1	S/D	—		—	
Aoridae						
Leptocheirus pinguis	30	S/D	13	136	0.65	6.80
Unciola irrorata	1	D				
Gammaridae						
Marinogammarus obtusatus	4	A	—		—	
Haustoridae						
Pontoporeia femorata	23	D	24	206	0.83	7.11
Lysianassidae						
Orchomenella minuta	1	D	—		—	
Melitidae						
Casco bigelowi	67	D	22	56	1.98	5.04
Maera danae	5	D	—		—	

Trophic group: A = algal scraper, D = deposit feeder, S = suspension feeder.

Table VII Species list, mean and maximum density (no./m^2) and biomass (g alcohol wet wt/m^2) of Gammaridea at station 82 for 14 seasonal samples (165 replicates) in 1978-1980.

	%	Trophic	Density, m^{-2}		Wet wt, g/m^{-2}	
Taxa	probability	group	Mean± 1SD	Max.	Mean	Max.
Ampeliscidae						
Haploops fundiensis	100	S	407± 352	2010	0.480	2.372
Byblis gaimardi	1	S/D	—	10	—	
Photidae						
Photis reinhardi	92	S	166± 106	610	0.191	0.702
P. pollex	2	S	—	20	—	
Phoxocephalidae						
Harpinia propinqua	87	D	46± 19	140	0.068	0.207
Phoxocephalus holbolli	<1	D	—	10	—	
Melitidae						
Casco bigelowi	57	D	13± 7	200	0.173	2.660
Melita dentata	4	D	—	40	—	
Maera loveni	2	D	1± 2.4	120		
M. danae	1	D	—	20	—	
Ischyroceridae						
Ischyrocerus anguipes	7	S	2± 1.9	50	0.004	0.106
I. megacheir	1	S	—	10	—	
Corophidae						
Erichthonius rubricornis	24	S	7± 9	70	0.009	0.095
Podoceridae						
Dyopedos monacanthus	50	S	23± 30	280	0.013	0.160
Lysianassidae						
Anonyx liljeborgi	7	D	3± 6	(50)?	0.007	0.115
A. debruyni	<1	D	—	10	—	
Hippomedon serratus	2	D	—	10	—	
H. propinquus	2	D	2± 7	240	0.032	3.840
Onesimus edwardsi	<1	D	—	10		
Orchomenella pinguis	7	D	0.8± 1	20	0.014	0.340
Melphidippidae						
Melphidipella macera	<1		—	10		
Calliopiidae						
Calliopius laeviusculus	<1	A	—	10	—	
Oedicerotidae						
Monoculodes edwardsi	<1		—	10	—	
Argissidae						
Argissa hamatipes	3	D	0.3± 0.5	20	0.001	0.030
Aoridae						
Leptocheirus pinguis	3	S	0.4± 0.9	10	—	
Pleustidae						
Stenopleustes inermis	1	D	—	10	—	

The probability of at least one individual per species in a 0.1 m^2 grab is given with a trophic group classification. S = suspension feeder, D = deposit feeder, A = algal scraper.

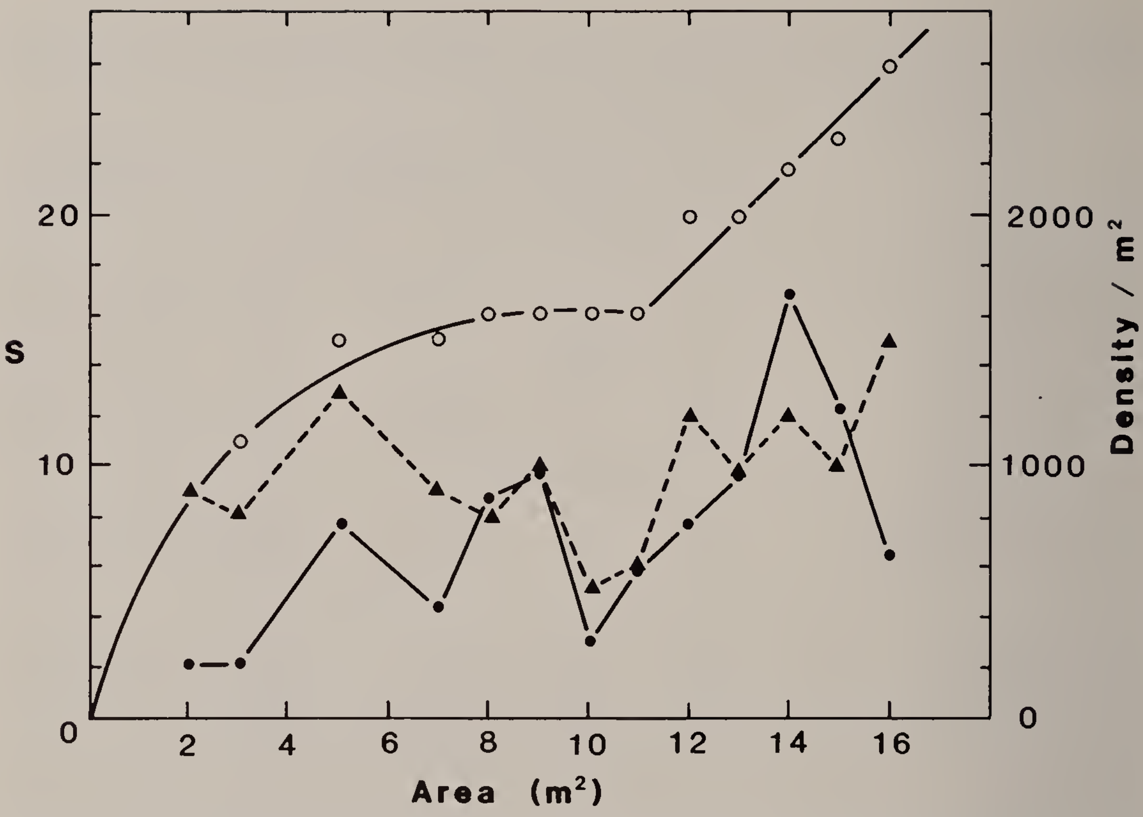

Fig 4 Gammaridean species/area curve for temporal sampling at station 82. Symbols: cumulative new species o, species per sampling date ▲, density/m^2 for each sample●.

of the species shown in Table VII indicated that subdominant species such as *Orchomenella pinguis* disappeared after January and the density of *Dyopedos monacanthus* was reduced until it disappeared after the April sampling. Species which appear in March and April for the first time and maintain high densities thereafter were *Hippomedon propinquus* and *Leptocheirus pinguis*. The pattern seen was thus one of species loss coupled with reduced density followed by replacement with new subdominant species and rapidly increasing density.

The probability of finding at least one individual of a given species was high for six species at Station 82. They include: *Haploops fundiensis, Photis reinhardi, Harpina propinqua, C. bigelowi, D. monacanthus*, and *Erichthonius rubricornis*. The characteristic species of this Station and indeed over much of the LaHave clay is *H. fundiensis*: it was found in all grab replicates at all times of the year with an average density at Station 82 of over 400 individuals/m^2.

Discussion

The known sublittoral, soft-sediment, gammaridean fauna for the Bay of Fundy is presented in the Appendix. A total of 99 species was recognized from concentrated geographic and seasonal sampling as well as from other samples of opportunity. All species present in the Bay of Fundy do not appear in the Appendix since we did not include known epifaunal gammarideans of rocks, fucoid or *Laminaria* beds or the gammarideans of suprabenthic and floating wrack communities. In general, the gammaridean fauna consists of subarctic and boreal elements in the Bay proper (e.g. *Gammarus setosus, Melita dentata*) and a few warm-water species in the estuarine upper Basins (e.g. *Ampelisca abdita, Stenopleustes gracilis*).

In a comparable study by Dickinson and Wigley (1981) on Georges Bank, a wider range of sampling devices was employed, including quantitative grabs, epibenthic sled nets, Dibby dredges, otter trawls, and fish-stomach analysis. These collection methods caught 97 species of gammaridean amphipods from 325 stations occupied. This compares with 55 species of gammarideans collected at 150 quantitative stations in the Bay of Fundy. Since the individual samples both within and between the two collections are not equivalent, it is not possible to compare the species diversity of the two areas based on equal sampling efforts. However, since our total sampling effort in the Bay of Fundy revealed at least 99 species of Gammaridea, we consider the two areas to be comparable in species richness.

The recognition of markedly increased densities and biomass of a few species of gammaridean amphipods in two estuaries receiving pulp mill wastes is consistent with previously reported information (Waldichuk & Bousfield 1962) and supports the concept of an enhanced zone of aerobic, heterotrophic production downstream from the anoxic/hypoxic zone (Poole *et al.* 1978). Some species (for example, *Gammarus oceanicus*) may be considered to be general indicators of eutrophication caused by nonspecific, organic pollution, although they are not present in anoxic or hypoxic zones.

That some of the most abundant species of gammaridean amphipods appear to be limited to one or two of the sediment types found in the Bay may be explained by physical factors, particularly tidal-current energy. For example, the Sambro sand stations support an impoverished macroinfaunal association (Wildish & Peer 1982), especially adapted to withstand high current speeds and sediment reworking of the sand substrate. A characteristic species present here is *Psammonyx nobilis* which, because of its excellent burrowing ability, is able to avoid the reworking of sandy sediment caused by high tidal currents. Dickinson and Wigley (1981) also found this species on the "shoals" region of Georges Bank in similar ecological conditions. The only other group identified by Dickinson and Wigley (1981) which showed concordance with co-occurring species of Bay of Fundy gammarideans was their "perimeter" group. This group only tolerates an annual temperature range between 4 and 13°C and is excluded from other parts of Georges Bank by warmer summer temperatures (up to 18°C). "Perimeter" species (including 14 of the 17 species listed by Dickinson and Wigley (1981) are: *Ampelisca macrocephala, Anonyx liljeborgi, Casco bigelowi, Corophium crassicorne, Dyopedos monacanthus, Erichthonius rubricornis, Harpinia propinqua, Hippomedon propinquus, Leptocheirus pinguis, Melita dentata, Phoxocephalus holbolli, Pleusmytes glaber, Protomedeia fasciata,* and *Stenopleustes gracilis*. These were found throughout the Bay of Fundy on all of the surficial sediment types. The limiting temperature hypothesis of Dickinson and Wigley (1981) provides a satisfactory reason for the restriction of many sublittoral species of Gammaridea to deeper water in the Bay because, in estuaries, the temperature range is wider (see Table V).

The difference in number of species of gammarideans at the shallow location (8 species) and deep location (16 or 26+ species) requires some explanation. Feeding conditions are probably better at the shallow location as evidenced by the much greater weight and length of *Casco bigelowi* there than at the deep location (Wildish 1980a, 1980b). Of the 3 dominant shallow species of gammarideans, all are medium to large as adults (15-25 mm body length) compared to the five adult dominants (3-6 mm body length) at the deep station. *Casco* also occurs at the deep station, and attains adult body lengths of up to 25 mm, although it occurs at a lower density and does not reach the same weight at maturity as in shallower water. We suggest that the shallow, inshore community is structured principally by physical factors, notably wave activity, which periodically removes two of the dominants, and by high temperatures during the summer, which limit colonization by cold-water stenotherms. Physical conditions are more stable at the deep location, with a narrow seasonal temperature range and less chance of wave activity near the bottom. Here the factors controlling the community are both physical (e.g. tidal current speed and suspension feeding) and biological in nature, including competition for food and avoidance of predators. The small size of most of the amphipods present here may be a successful adaptation to avoid fish predators.

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Appendix: Sublittoral Gammaridea from the Bay of Fundy

Single asterisks indicate that the specimen was sampled from a fish stomach, double asterisks indicate a new addition to the Canadian faunal records. Preserved material is deposited in the Atlantic Reference Centre collection, Biological Station, St. Andrews, N.B., E0G 2X0.

Acanthonotozomatidae
  Acanthonotozoma serratum (Fabricius, 1780)*
Ampeliscidae
  Ampelisca abdita Mills, 1964**
  A. vadorum Mills, 1963
  A. macrocephala Lilljeborg, 1852
  A. aequicornis Bruzelius, 1859
  Byblis gaimardi (Kroyer, 1846)
  Haploops fundiensis Wildish and Dickinson, 1982**
  H. setosa Boeck, 1871
Aoridae
  Leptocheirus pinguis (Stimpson, 1853)
  Unicola inermis (Shoemaker, 1942)
  U. irrorata Say, 1818
  U. leucopis (Kroyer, 1845)
Argissidae
  Argissa hamatipes (Norman, 1869)
Calliopiidae
  Calliopius laeviusculus (Kroyer, 1838)*
  Halirages fulvocinctus (Sars, 1854)*
Corophidae
  Corophium bonelli (Milne-Edwards, 1830)
  C. crassicorne Bruzelius, 1859
  C. acherusicum Costa, 1857
  C. tuberculatum Shoemaker, 1934
  C. volutator (Pallas, 1766)
Dexaminidae
  Dexamine thea Sars, 1893*
Eusiridae
  Eusirus cuspidatus Kroyer, 1838*
  Rhachotropis oculata (Hansen, 1887)*
Gammarellidae
  Gammerellus angulosus (Rathke, 1843)*

Gammaridae
  Gammarus lawrencianus Bousfield, 1956*
  G. mucronatus Say, 1818
  G. oceanicus Segerstrale, 1947
  G. setosus Dementieva, 1931
  Marinogammarus obtusatus Dahl, 1936
Haustoriidae
  Acanthohaustorius millsi Bousfield, 1965**
  A. spinosus Bousfield, 1962
Isaeidae
  Gammaropsis maculatus Johnston**
  G. melanops G.O. Sars, 1882
  Photis macrocoxa Shoemaker, 1945
  Podoceropsis nitida (Stimpson, 1853)
  Protomedeia fasciata (Kroyer, 1842)
Ischyroceridae
  Erichthonius difformis Milne-Edwards, 1830
  E. rubricornis (Smith, 1873)*
  Ischyrocerus anguipes Kroyer, 1838
  I. megacheir (Boeck, 1871)
  Jassa falcata (Montagu, 1808)*
Lafystiidae
  Lafystius sturionis Kroyer, 1842
Lysianassidae
  Anonyx debruyni Hoek, 1882
  A. liljeborgi Boeck, 1870
  A. sarsi Steele and Brunel, 1968
  Hippomedon propinquus Sars, 1890
  H. serratus Holmes, 1903*
  Menigrates obtusifrons (Boeck, 1861)**
  Onesimus edwardsi Kroyer, 1842
  Onesimus normani (Sars, 1890)*
  Orchomene depressa Shoemaker, 1930
  Orchomenella minuta Kroyer, 1846
  O. pinguis (Boeck, 1861)
  Psammonyx nobilis (Stimpson, 1853)
  Tmetonyx caeculus (Sars, 1890)
  T. cicada (Fabricius, 1780)
Melitidae
  Casco bigelowi (Blake, 1929)
  Maera danae Stimpson, 1853
  M. loveni (Bruzelius, 1859)
  Melita dentata (Kroyer, 1842)
  N. nitida Smith, 1873**
  M. n.sp.
Melphidippidae
  Melphidippa goesi Stebbing, 1899*
  M. macera (Norman, 1869)
Pontoporeiidae
  Amphiporeia lawrenciana Shoemaker, 1929
  Bathyporeia quoddyensis Shoemaker, 1949
  Pontoporeia femorata Kroyer 1842

Oedicerotidae
  Aceroides latipes (G.O. Sars, 1882)
  Monoculodes edwardsi Holmes, 1903
  M. intermedius Shoemaker
  M. latimanus (Goes, 1866)
  M. norvegicus (Boeck, 1861)
  M. packardi (Boeck, 1861)
  M. tesselatus Schneider, 1884
  M. tuberculatus Boeck, 1861
  Westwoodilla brevicalcar (Goes, 1866)
Paramphithoidae
  Paramphithoe hystrix Bruzelius, 1858
Phoxocephalidae
  Harpinia crenulata Boeck, 1871
  H. propinqua Sars, 1895
  H. truncata G.O. Sars, 1895
  Phoxocephalus holbolli (Kroyer, 1842)
Pleustidae
  Neopleustes pulchellus (Kroyer, 1846)
  Pleusymtes glaber (Boeck, 1861)*
  Pleustes panoplus (Kroyer, 1838)
  Stenopleustes gracilis (Holmes, 1905)**
  Stenopleustes inermis (Shoemaker, 1949)
Podoceridae
  Dyopedos arcticus (Murdock, 1884)
  D. monacanthus (Metzger, 1875)
  D. porrectus (Bate, 1857)
  Paradulichia typica Boeck, 1870
Pontogeneiidae
  Pontogeneia inermis (Kroyer, 1842)
Stegocephalidae
  Stegocephalus inflatus Kroyer, 1842
Stenothoidae
  Metopa alderi (Bate, 1857)
  M. boecki G.O. Sars, 1892
  Metopella angusta Shoemaker, 1949
  M. carinata (Hansen, 1887)
  Stenothoe minuta Holmes, 1905
Tironidae
  Syrrhoe crenulata Goes, 1866

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APPLICATION OF ^{13}C NMR SPECTROSCOPY IN THE ASSIGNMENT OF ^1H NMR SIGNALS OF NONEQUIVALENT SCH_3 GROUPS

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The SCH_3 groups of 3- and/or 5 alkyl substituted 2,4,6-trithiaheptanes have almost identical chemical shifts in both ^1H and ^{13}C nmr spectra. A combination of gated decoupling and single-frequency off-resonance decoupling, followed by the construction of graphs of the type proposed by Pachler, allows the assignment of the ^1H nmr signals.

Les graphes SCH_3 des composés 2,4,6-trithiaheptanes substitués en position 3 et 5 par des groupes alkyls ont des déplacements chimiques presque identiques dans leurs spectres rmn au ^{13}C et ^1H. Une combinaison de découplage à fenêtre et de découplage à frequence unique hors-résonance, suivie par la construction de graphiques de type proposé par Pachler, permit l'attribution des signaux rmn ^1H.

The ^1H and ^{13}C nuclear magnetic resonance spectra of the 2,4,6-trithiaheptanes Ia-e provide some examples of a familiar problem in the interpretation of nmr spectra. The problem, common to compounds with several chemically nonequivalent –OR, –SR, or $–NR_2$ groups, is the assignment of singlet resonances with very small chemical shift differences, and is illustrated here by the assignment of the nonequivalent $S\text{-}CH_3$ groups of Ib and Ic. In both these examples the C-1 and C-7 $S\text{-}CH_3$ signals are sharp singlets in both the usual fully decoupled ^{13}C spectrum and in the ^1H spectrum, with such a small range of chemical shifts observed for the series Ia-e that assignments based on the effect of substituents on chemical shifts must be questionable. There are many reports (Freeman and Hill 1971, Shaw 1973) on the correlation of ^{13}C spectra with ^1H spectra followed by assignment of the ^{13}C spectrum from easy assignment of the ^1H spectrum, and a few cases have been reported (Luzikov *et al.* 1975, McCabe and Nelson 1976) in which the ^1H spectrum has been assigned from correlation with an easily interpreted ^{13}C spectrum. We report an example in which neither ^1H or ^{13}C spectrum is readily assigned, yet both assignments are accessible from various combinations of decoupling experiments.

The starting point of our assignment is the observation that in the ^{13}C spectrum of Ia, measured under conditions of gated decoupling, (Feeney *et al.* 1970) the $S\text{-}CH_3$ signal is a quartet ($J = 139.0$ Hz) of triplets ($J = 4.7$), with the triplet splitting the result of the three-bond proton-carbon coupling through sulfenyl sulfur. In Ib and Ic the gated decoupling gives a quartet ($J = 138.9$) of triplets ($J = 4.5$) for C-7, while C-1 appears as a quartet ($J = 138.8$) of doublets ($J = 4.0$ for Ib, $J = 4.2$ for Ic). Hence, the gated decoupling experiment acts as a probe of the asymmetry of the molecule and the ^{13}C spectrum may be assigned.

Correlation of the ^1H and ^{13}C spectra was made for each compound from measurement of a series of 6-8 off-resonance decoupled spectra with a different value of the decoupling frequency for each spectrum of the series. These spectra yield values of J_{RED}, the residual directly bonded carbon-proton coupling constant, as a function of decoupling frequency. These J_{RED} measurements are then used to construct plots of the type proposed by Pachler (Pachler 1972) in which values of the ratio $J_{RED}/(J^2_o - J^2_{RED})^{1/2}$, where J_o is the magnitude of the directly bonded C-H coupling constant measured in the gated decoupling experiment, are plotted *vs* decoupler frequency, with the zero intercept on the x-axis giving the resonance frequency of the directly bonded proton. This method has been showed valid (Pachler 1972) for values of $\frac{\gamma Hz}{2\pi} >> 1/2|J_o - J_{RED}|$, a condition easily satisfied by the maximum decoupler power of the Varian CFT-20 spectrometer. The plots were excellent straight lines over a range of decoupling frequencies 1000 Hz on either side of the resonance frequency and the intercepts were determined by linear regression analysis. The assignments Ib and Ic agree with what might be expected, in that substitution at C-3 should affect the chemical shift of C-1 protons more than that of C-7 protons, however the real test of the method is the assignment of S-CH_3 proton signals in Id and Ie. Id and Ie were prepared as a diastereometric mixture and all spectra recorded on solutions of mixture. The graphical method predicts the signal of the S-CH_3 protons for the major product Id and the minor product Ie. These are easily distinguished by the relative peak areas and the experimental measurement places Ie 4.8 Hz above Id. The usual plots of J_{RED} *vs* decoupler frequency (Birdsall *et al.* 1981), even for much narrower ranges of decoupling frequency, were much less accurate and could give misleading results in cases such as this where chemical shift differences are small.

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The assignment method outlined here should be applicable to other $-SCH_3$, $-OCH_3$, or $-N(CH_3)_2$ examples for which an internal asymmetry of the molecule may be exploited to assign the ^{13}C spectrum. It is particularly applicable to cases for which chemical shift differences are so small that low-power selective decoupling is impractical, and for which 2-D experiments would require inordinate spectrometer time in order to achieve the resolution needed.

Experimental

^{13}C nmr spectra were recorded at 20 MHz and ^1H nmr spectra recorded at 80 MHz using a Varian CFT-20 spectrometer. The same solution containing 100-250 mg/ml $CDC1_3$ was used for both sets of spectra. The fully decoupled ^{13}C spectra were recorded with a spectral width of 4000 Hz and the gated decoupling experiments were carried out with the smallest possible spectral width for which "foldover" of spectral lines could be avoided, typically 1000 Hz. The preparation and characterization of compounds Ia-e has been reported on elsewhere (Grossert *et al.* 1981).

Table I

S-CH_3 signals in the ^1H and ^{13}C NMR spectra of 2,4,6-Trithiaheptanes $CH_3SCHRSCHR'SCH_3$

Compound	R	R	$\delta_{^{13}C}$(C-1)	$\delta_{^{13}C}$(C-7)	$\delta_{^1H}$(C-1)	$\delta_{^1H}$(C-7)
Ia	H	H	14.19		2.15	
Ib	Me	H	11.34	14.23	2.10	2.16
Ic	Bu^n	H	12.12	14.98	2.05	2.15
Id	Me	Me	12.8		2.16	
			(major diastereomer)			
Ie	Me	Me	11.3		2.10	
			(minor diastereomer)			

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OBSERVATIONS ON THE SEABIRDS OF MANAWAGONISH ISLAND, NEW BRUNSWICK: MOVEMENTS AND POPULATION CHANGES 1940-1983[1]

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Since 1940, significant changes in the population of seabirds nesting on Manawagonish Island, New Brunswick, have been observed. Most notably there were large increases in the numbers of nesting great black-backed gulls, Larus marinus, and double-crested cormorants, *Phalacrocorax auritus.* Dispersal patterns for herring gulls, *L. argentatus*, from this colony show a late summer and early fall movement northward into the Northumberland Strait and Gulf of St. Lawrence, as well as southward travel as far as the Gulf of Mexico and a summer concentration around Cape Cod. During the winter months birds appear to congregate in metropolitan areas between Long Island and Philadelphia.

Depuis 1940, des changements importants dans les populations d'oiseaux de mer nichant sur l'île Manawagonish, au Nouveau-Brunswick, ont été observés; le changement le plus notable étant l'augmentation considérable dans le nombre de Goélands à manteau noir, *Larus marinus*, et de Cormorans à aigrettes, *Phalacrocorax auritus*, nichant en ce lieu. Les modes de dispersion des Goélands argentés, *L. argentatus*, en provenance de cette colonie, indiquent que vers la fin de l'été, début de l'automne, il y a un mouvement de ces oiseaux vers le Nord, en direction du détroit de Northumberland et du golfe Saint-Laurent, en plus d'un mouvement vers le Sud, aussi loin que le golfe du Mexique, et que, en été, une concentration particulière de ces même oiseaux se trouve dans la région de Cape Cod. Pendant les mois d'hiver, ils semblent se rassembler dans les régions métropolitaines de Long Island et de Philadelphie.

Introduction

Significant population changes in a number of seabird species have been documented in Atlantic Canada since the end of the last century. Christie (1979), for example, summarizes changes that have been recorded in Maritime populations of the gannet, *Morus bassanus*, great and double-crested cormorants, *Phalacrocorax carbo* and *P. auritus*, and in herring, great black-backed and laughing gulls, *Larus argentatus*, *L. marinus* and *L. atricilla*. Amid escalating exploitation of the marine resources of the Fundy region, this information, as well as data on patterns of movement such as that provided by Brown et al. (1975) and Brown (1977), may prove valuable in reducing industry-related seabird mortality. Nevertheless, Able (1983) notes that in North America we have remarkably little detailed information on the migration routes and destinations of specific population of birds. Here we report on dispersal patterns, with particular reference to herring gulls, and on population changes observed over a 43-year period in great black-backed gulls, double-crested cormorants and great blue herons, *Ardea herodias*, nesting on Manawagonish Island, New Brunswick, a seabird colony adjacent to the port of Saint John. Both Brown et al. (1975) and Markham (1978), who reviewed the status of the double-crested cormorant in Canada, were apparently unaware of the existence of the Manawagonish Island cormorant colony.

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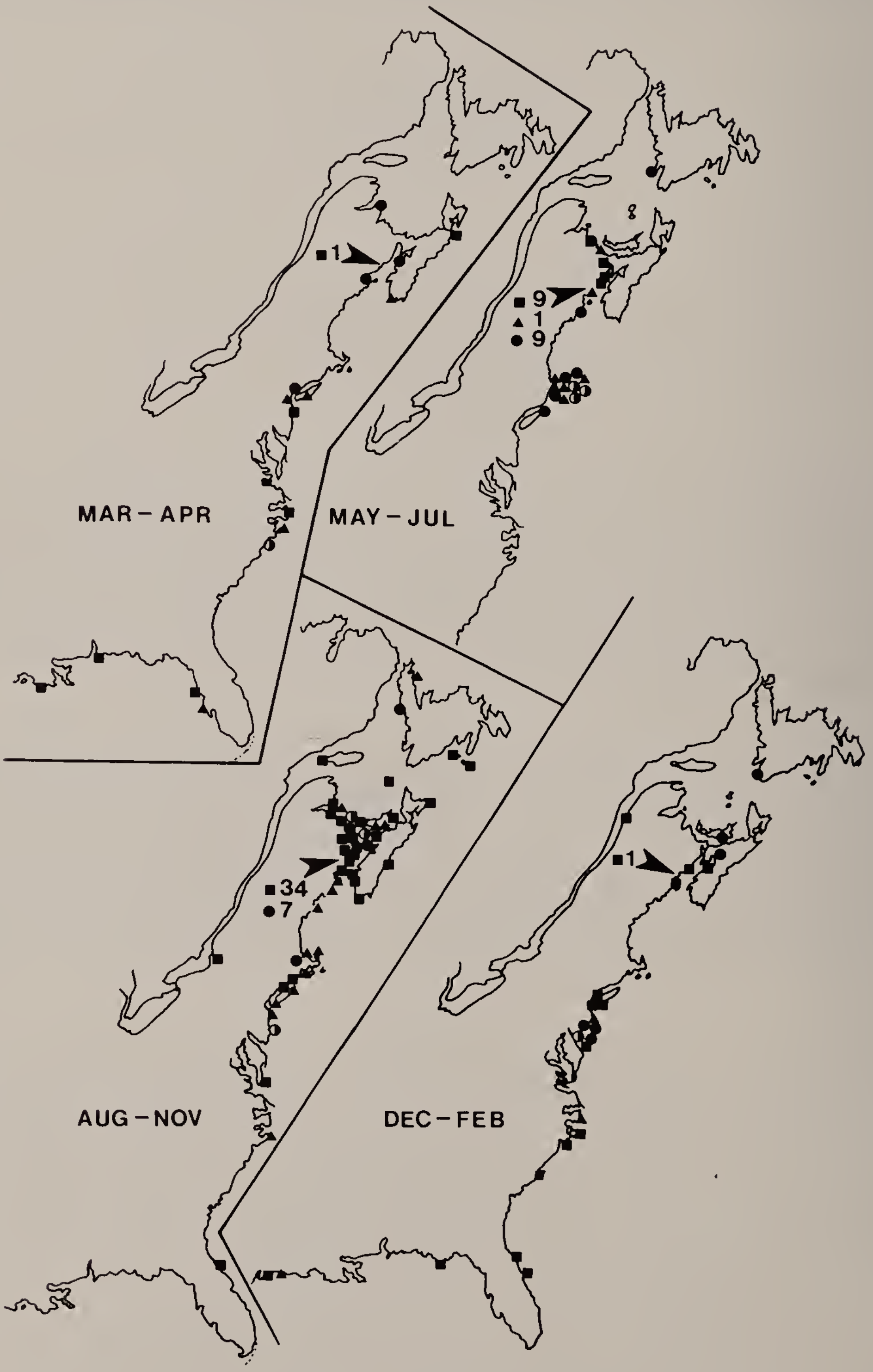

Fig 1 Band returns for herring gulls fledged from Manawagonish Island, New Brunswick. Squares show first-year birds, triangles second-year birds, half-open circles third-year birds and solid circles adults. Arrow and preceding symbols record returns from banding site.

Methods

From 1940 to 1983, we banded over 5200 fledgling herring gulls, more than 1100 great black-backed gulls and at least 200 double-crested cormorants on Manawagonish Island (lat. 45° 12′, long. 66° 06′) and its small satellite, Thumb Cap Island, in the lower Bay of Fundy. Together Manawagonish and Thumb Cap Island occupy less than 20 hectares and are located 1.5 km offshore. Unfortunately we are unsure as to precisely how many birds were marked, since before 1955, records for this study by Astle, the Canadian Wildlife Service, and the U.S. Bird Banding Laboratory are incomplete with regard to total birds banded. Banding was carried out on one day in July or August during 38 of the nesting seasons from 1940 to 1983 using aluminum leg bands provided by the U.S. Fish and Wildlife Service to Astle. For inspection, band returns have been divided into four periods; May-July (breeding), August-November (post-breeding dispersal), December-February (wintering), and March- April (pre-breeding).

Results and Discussion

Patterns of movement for herring gulls banded on Manawagonish Island are based on 172 returns (Fig 1). Individuals of all ages, but particularly first-year birds, wander widely along the eastern seaboard and into the Gulf of Mexico during the winter and spring months. During the summer and fall, adult and immature herring gulls from Manawagonish Island congregate in the Cape Cod region, but during the winter months this concentration seems to shift south to metropolitan areas between Long Island, New York and Philadelphia. Drury and Nisbet (1972) estimated that 34% of the east coast population of herring gulls congregated about New York during the winter of 1965 and Threlfall (1978) found that New York was the prime wintering area for herring gulls banded in Newfoundland. During the late summer and autumn there is a northward movement of herring gulls up the Bay of Fundy and across the Isthmus of Chignecto to Northumberland Strait and the east coast of New Brunswick and as far as Newfoundland. Both adult and immature birds from the Manawagonish Island colony also spend the winter months in these regions. Such northward movement by young herring gulls following the breeding season appears to be characteristic of eastern North American herring gull colonies (Gross 1940, Moore 1976, Threlfall 1978). Judging from our returns, as well as those of birds banded in Newfoundland (Threlfall 1978) and about the Great Lakes (Moore 1976), the entire Gulf of St. Lawrence seems to be important in the late summer and early fall movements of the Eastern Canadian herring gull population. Large numbers of birds are likely dispersed over the region during this period and the many small fishing harbours, shallow lagoons and estuaries undoubtedly provide good feeding sites.

Based on movements by first-year birds in January-February, Burger (1981) found gull colonies following one of two general dispersal patterns; either long distance or short distance. She found that gulls from England, Denmark and Jamaica Bay, New York were short-distance migrants, usually remaining within 200 km of the natal colony. Birds banded at colonies in the Great Lakes, Newfoundland, Maine and Finland were identified as long-distance dispersers. The Manawagonish Island colony seems to fit the latter pattern, being characterized by long-distance movement by first-year birds in January-February (range 75-3,075 km, $X = 1{,}268$ km; $n = 7$).

Our returns for great black-backed gulls ($N = 35$) and double-crested cormorants ($N = 14$) are few and are therefore not illustrated. For both species there is an indication of some northward movement into the Northumberland Strait following the breeding season, coupled with long-distance southward flights during the same period and throughout the winter (maximum distance GBBG=2,360 km, DCC=2,200 km). Some great black-backed gulls fledged from Manawagonish Island spend the winter months on the New Brunswick coast as well.

Since 1940 when our banding began, Drury and Nisbet (1972) have recorded shifts in herring gull demography and Cannell and Maddox (1983) have reported a significant decline in the number of herring gulls nesting on Kent Island, New Brunswick, principally between 1950 and 1965. Unfortunately our (small number of) returns have not allowed us to identify how these changes may have affected the Manawagonish Island colony, which now includes over 400 pairs of herring gulls (A.R. Lock, Canadian Wildlife Service, Dartmouth, N.S., pers. comm.). When banding was first initiated (1940) great black-backed gulls (3 pairs) nested only on Thumb Cap Island and this island is now dominated by black-backs. Pettingill (1939) reported that the great black-backed gull only began as a common nesting species in the Grand Manan Archipelago in the late 1930's, although he cites a Kent Island record as early as 1933, this being the first recent breeding record for New Brunswick. By 1952, Squires (1952) was able to report this gull was breeding commonly on most of the islands in the Bay of Fundy. Since 1963 we have banded 77-170 black-backs annually on Manawagonish and Thumb Cap islands. Canadian Wildlife Service (1979) surveys indicated 107 pairs of black-backed gulls on the two islands in June of 1979 (A.R. Lock pers. comm.). Great blue herons were first noted nesting (2 pairs) on Manawagonish Island by Astle in 1948 (Squires 1952). Squires (1976) reported about 40 nests on Manawagonish Island in 1963, and CWS (1979) surveys revealed a minimum of 44 active nests in 1979 (A.R. Lock pers. comm.). Mendall (1936) and Gross (1944) have documented the increase in double-crested cormorants in this area after their disappearance in the 19th Century. When banding began in 1940, only 30 pairs of double-crested cormorants nested on Manawagonish Island and cormorants have never been observed nesting on Thumb Cap. The colony included 2023 active nests in trees in June of 1979 (A.R. Lock pers. comm.). Until 1978 cormorants had always been observed nesting in the trees but in that year the first ground nesting was discovered on the northern end of the island. Extensive tree deaths and colony expansion are no doubt the reason. While banding in 1983 we observed that large numbers of cormorant nests were located on the ground. Preliminary observations indicate that birds nesting early in the season select trees, while late nesters are forced to choose ground locations.

Acknowledgements

We are most grateful to the many members of the Saint John Naturalists Club who have assisted with banding over the years. D.S. Christie provided critical comments on early versions of this manuscript that lead to its considerable improvement and A.R. Lock generously provided information from his unpublished seabird surveys on Manawagonish and Thumb Cap islands. Computer print-outs of banding recovery data were kindly supplied by the Canadian Wildlife Services, Ottawa.

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DISCOVERY OF AN EXTENSIVE AREA OF *LAMINARIA SACCHARINA* IN MINAS BASIN, NOVA SCOTIA

Air photos taken along the shoreline of western Minas Basin, Nova Scotia, during an extreme low tide on 20 August 1978 revealed an extensive bed of *Laminaria saccharina* extending from Cape Blomidon southwards for approximately 8 km to Medford Beach (Fig 1). Because of the natural turbidity of these waters, the full width of the bed could not be determined from the air but was 300 to 400 metres wide at several places. Although our "scientific community" was unaware of the macrophyte beds of this magnitude, subsequent enquiries revealed that local fishing draggers purposely avoid this heavy seaweed area, and local residents seasonally harvest a lucrative dulse (*Palmaria palmata*) crop from within this *Laminaria* zone. Over 20 other species of algae are in this community including *Chondrus crispus* and *Corallina officinalis*.

The substrate over much of this area is ledges of Blomidon shale but the *Laminaria* holdfasts also attach to loose stones, an indication of the low energy aspect of

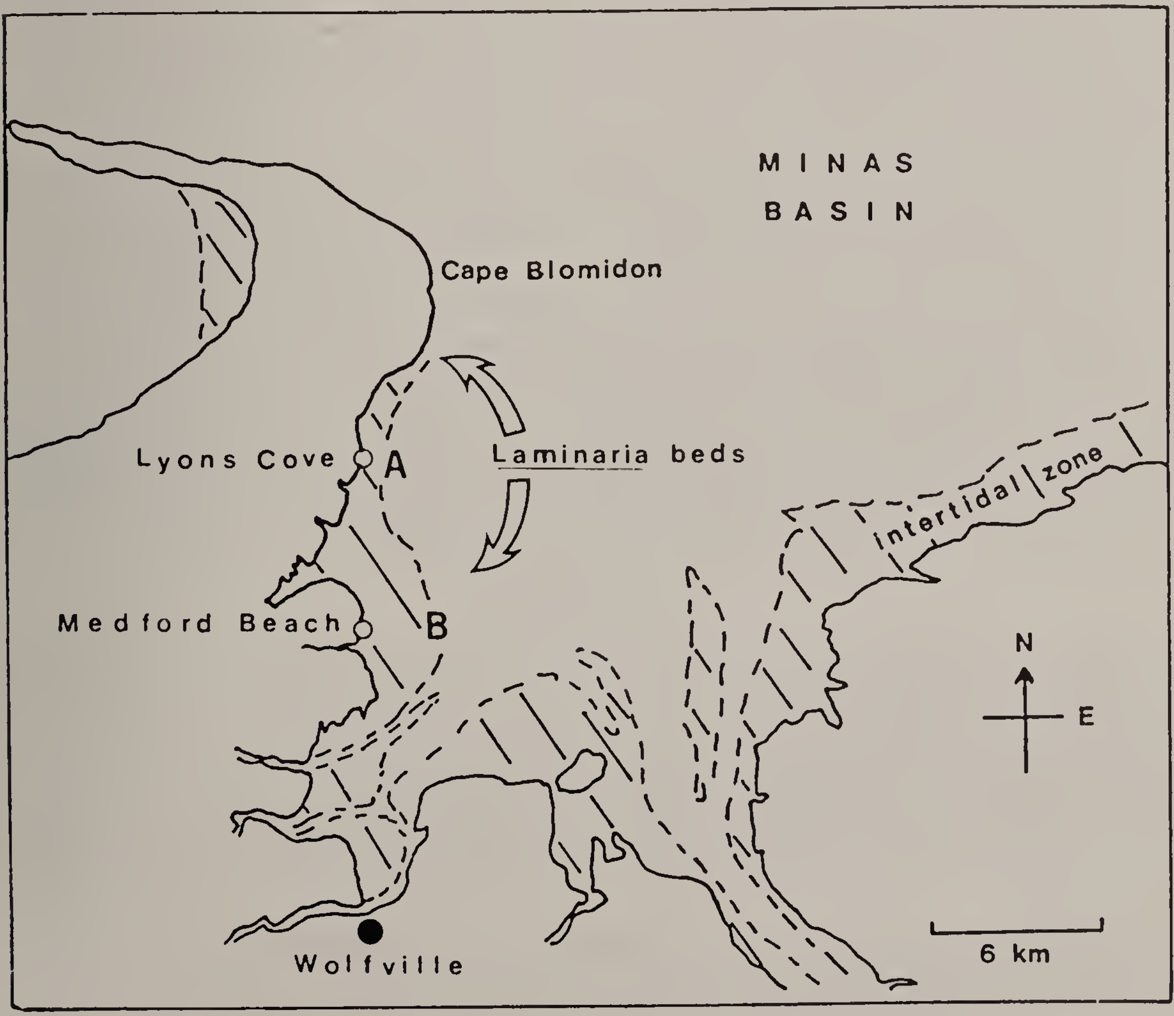

Fig 1 Western area of Minas Basin, indicating extent of *Laminaria saccharina* beds.

this shoreline. In fact, one reason the discovery of the beds was so surprising, is that *Laminaria* plants rarely are found at the strand line in this part of Minas Basin. Off Medford Beach, *Laminaria* even attaches to stones partially buried in the sands of an extensive megaripple area.

In the summer of 1980, growth rates of 204 of these intertidal (from 0 to 0.8 m above Datum) *Laminaria* were measured. The blades were generally 0.5-2 m in length, and, following the method of Mann (1973), a 5 mm hole was punched in the blade 10 cm from the junction of stipe and blade. Blades were then remeasured on the subsequent spring tides to determine the rate at which the hole was receding from the stipe junction. Few marked blades were found more than once as many plants attached to small rocks had been moved about during the intervening time. Therefore additional blades were punched on each field trip.

From mid-May to the end of July, linear growth was constant at about 1.1 cm/day. This was followed by a small (but significant, t-test, $p < 0.05$) decline to 0.9 cm/day during August.

In St. Margaret's Bay on the Atlantic coast of Nova Scotia, Craigie and Chapman (1977) determined that growth of *Laminaria* was related to nitrogen availability. They found a summer decline in growth rate following the depletion of nitrate reserves in the plant tissues, and a growth resurgence in late winter when relatively high concentrations of dissolved nitrates were in the water column. Artificial nitrate enrichment demonstrated that *Laminaria* could maintain a high growth rate throughout the summer. In Minas Basin, however, nitrate concentrations are high throughout the year (Keiser *et al.* in press) and should not be a limiting factor for algal growth.

Mann (1973) determined that grazing by sea urchins (*Stronglyocentrotus droebachiensis*) and periwinkles (*Littorina littorea*) accounted for not more than 10% of the net production of the seaweeds in St. Margaret's Bay. The remaining 90% eventually entered food chains as particulate or dissolved organic matter. In Minas Basin, the 90% figure is undoubtedly exceeded as sea urchins are rarely found in this area of Minas Basin and periwinkles are relatively scarce at these algal beds. On the Atlantic coast of Nova Scotia, *Laminaria* produce about 1200-1800 g C/m^2/yr with annual growth of about 200 cm/plant (Mann 1972). As Minas Basin beds may exceed those calculations, it is evident that future modeling of the Minas Basin ecosystem will require firm figures of the dimensions of this algal area and calculations of its potential as a significant source of detritus.

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THE BLUNTHEAD PUFFER, *SPHOEROIDES PACHYGASTER* (MULLER AND TROSCHEL, 1848) (PISCES: TETRAODONTIDAE) NEW TO NOVA SCOTIA AND CANADA

The puffers (Tetraodontidae) are small stout-bodied fishes which, when threatened, inflate a sac-like expansion of the gullet, dramatically expand their size and become spherical in shape. Two species, the oceanic puffer, *Lagocephalus lagocephalus* (Linnaeus, 1758), and the northern puffer, *Sphoeroides maculatus* (Bloch and Schneider, 1801), have been previously reported in Canadian waters. We follow the format of Leim and Scott (1966) in our description of the blunthead puffer, *Sphoeroides pachygaster*, the most recently reported species of puffer for Canadian inshore waters.

Blunthead puffer, *Spheroides pachygaster* (Müller and
Troschel in Schomburgk, 1848)
Sphéroïde trogne (m.)

Description

Body depth, when not inflated, about 3.1 in standard length (SL), rounded, deepest anteriorly, venter tapering from beneath eye to caudal peduncle. Head length about 2.5 in SL; upper profile bluntly rounded, lower profile nearly vertical; bony interorbit wide, 15% of SL; snout length long, 20% of SL; gill slit large, extending from above pectoral base to pectoral insertion, about 1.3 times orbit diameter and running obliquely posteroventrally, nostrils with small pores in either end of transverse tubes. Mouth terminal, small; teeth wanting, but paired premaxillaries and dentaries give appearance of four large incisiform teeth. Eye small, ovoid, horizontal diameter or orbit greatest, 11 in head.

Fins: (We follow Ship and Yerger (1969a) in the counting method for fin rays; counts for our specimen are followed by values in brackets from Martin and Drewry (1978). Dorsal (1) 8 [8-9], base approximately 2 in height and also in orbit, origin in posterior quarter of body; caudal moderately large, rounded; anal (1) 9 [8-9], base 2 in height and also in orbit, origin in posterior quarter of body and beneath dorsal insertion; pectorals moderate, 15:15 [14-18], base 1.3 in length, equal to orbit. No visible lateral line. Scales and prickles wanting. Vertebrae (including urostyle) 19.

Colour

In alcohol, grey above, paler on venter and with venter of caudal peduncle milky white. Dorsal and lateral surfaces with random dark grey spots from caudal peduncle to interorbit. Snout and chin with a few scattered melanophores, a prominent large black spot on either side of dorsal base. Pectorals and anal translucent white and without markings, dorsal light dusky grey, caudal dark dusky grey but with tips of rays and lower margin lighter.

Distinctions

In overall appearance similar to the oceanic puffer, *Lagocephalus lagocephalus*, but with seven fewer dorsal and five fewer anal rays and also lacking the ventral skin spines typical of the oceanic puffer. It is readily distinguished from the northern puffer, *Sphoeroides maculatus*, by the lack of prickles anywhere on the body, by the lack of 6-8 vertically elongate dark bars on the body behind the pectoral fin, and by its steep anterior profile.

Size

Length reported to 14 inches (=35.5 cm) by Jordan and Evermann (1898), but Martin and Drewry (1978) reported its maximum as 250 mm. Our specimen was 107 mm SL but shrank to 103 mm SL, 118 mm total length, and 48 grams by November 1984.

Range

According to Shipp and Yerger (1969b) *S. pachygaster* is found in most of the warmer western Atlantic, but published records of its occurrence are few. Martin and Drewry (1978) reported its range as New Jersey throughout western Atlantic to Argentine, 37°S and from much of the African Atlantic and Indian Ocean coasts, probably Nigeria to Natal; also known from St. Helena Island in the Atlantic and from the Philippines and Hawaii in the Pacific. To the best of our knowledge the blunthead puffer has not been recorded previously from Canada.

Canadian Distribution

This specimen was captured in a trap net in Eastern Passage, Halifax County, Nova Scotia (44°37′N, 63°30′W) by Jerome Henneberry on 10 October 1974. It is catalogued in the National Museum of Natural Sciences, National Museums of Canada, Ottawa as NMC 75-0021.

Biology and Economics

Most puffers are inshore fishes, but the blunthead puffer is a relatively deepwater species, 30-100 fathoms (Ship and Yerger, 1969b), with adults in 25-480 m, most deeper than 100 m (Martin and Drewry, 1978). We have no information on its habits or food and Martin and Drewry (1978) report that there is no information on spawning, larvae, juveniles, growth or age and size at maturity.

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The authors thank Jerome Henneberry for donating the blunthead puffer. Mrs. Jadwiga Frank, National Museum of Natural Sciences, Ottawa, made the radiograph, Ron Merrick, Media Services, Provincial Library, Halifax, took the photograph, and Doris Cruikshank, Nova Scotia Museum, typed the manuscript.

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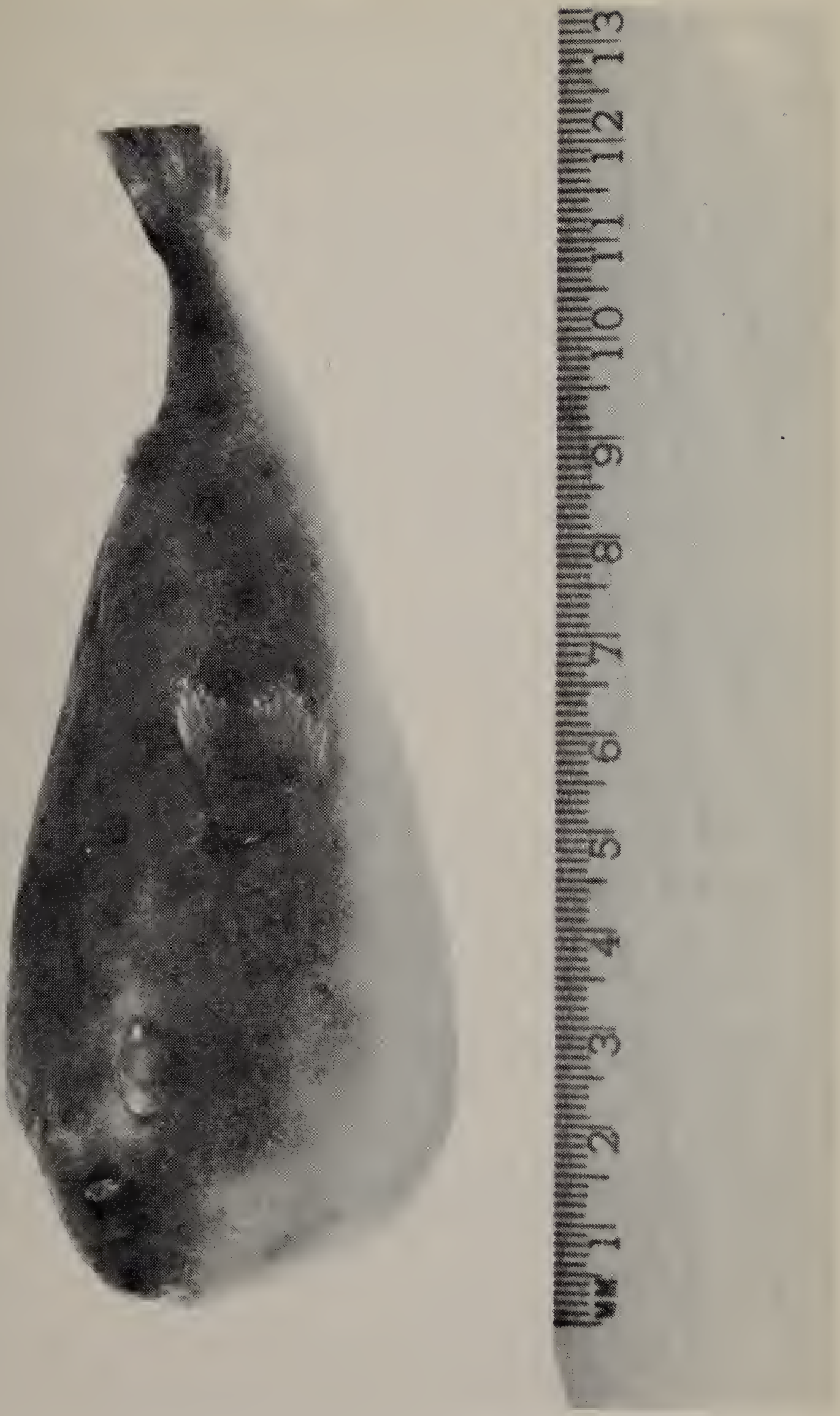

Fig 1. Blunthead puffer, *Sphoeroides pachygaster*, captured in a trap net in Eastern Passage, Halifax County, Nova Scotia by Jerome Henneberry on 10 October 1974.

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RANGE EXTENSION OF LITTLE BLUESTEM *ANDROPOGON SCOPARIUS* *(SCHIZACHYRIUM SCOPARIUM)* IN NOVA SCOTIA[1]

On 26 October, 1984 while collecting specimens of evening primrose *Oenothera biennis* from a roadside embankment on highway 10 near Cherryfield, Lunenburg Co., Nova Scotia, I came upon two clumps of little bluestem, *Andropogon scoparius* (Michx). The first plant was approximately 50 cm in diameter and the second 30 cm. Specimens were collected and deposited in the herbaria of the Kentville Station, Acadia University (ACAD) and Agriculture Canada Ottawa (DAO). This finding probably is an introduction and does not represent a prairie refugium.

An examination of the specimens at Acadia University revealed that a collection (31293) by G.C. Warren in August 1942 from Wolfville, Nova Scotia had been assigned to this species by E.W. Hart Jr. The specimen is very fragmentary with only three florets. Possibly for this reason Roland and Smith (1964) did not include this species in their flora. Scoggan (1978) refers to the Wolfville collection in the Flora of Canada. Macoun reported it from Goat Island of Grand Lake Area, New Brunswick as early as 1883.

Gould (1967) brought to the attention of North American botanists the need for revising the genus *Andropogon* based on the more extensive knowledge of taxonomists who had worked on the many related species found especially in Africa and Asia. Hence we now find this species in recent manuals and floras referred to as *Schizachyrium scoparium* (Michx.) Nash.

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Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. Metric units, SI units and decimals should be used whenever possible. Use day/month/year sequence for dates. Do not use periods after such abbreviations as "mm, kg, DOE, NRC, etc."

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EXPERIMENTAL STUDIES OF THE EFFECTS OF ACIDITY AND ASSOCIATED WATER CHEMISTRY ON AMPHIBIANS

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Laboratory bioassays with 5 species of Nova Scotian amphibians (*Ambystoma maculatum, Hyla crucifer, Rana sylvatica, R . palustris,* and *Bufo americana*) and *Xenopus laevis* revealed pH 4.0 to 5.0 as the critical range within which developing embryos showed reduced hatching success, and below which hatching did not occur. Bioassays revealed differences in acid tolerance among various species of Nova Scotia amphibians. For some species, aluminum in combination with pH<5, had a deleterious effect. Calcium ameliorated pH toxicity, but in some cases mortality was increased at very high Ca concentrations (≥50 ppm). Larvae of *Rana clamitans* and adult *Notophthalmus viridescens* survived exposure to pH as low as 3.3, but this tolerance was reduced at low temperatures.

Des bioessais portant sur 5 espèces d'amphibiens de la Nouvelle-Ecosse (*Ambystoma maculatum, Hyla crucifer, Rana sylvatica, R. palustris* and *Bufo americana*) et *Xenopus laevis* ont montré que le pH 4.0 à 5.0 constitue une zone critique à l'interieur de laquelle le taux d'éclosion était réduit. Au-dessous de cette zone l'eclosion ne se produisait pas. Des bioessais ont montré des différences spécifiques de tolérance à l'acide. Le calcium réduisant la toxicité associé au bas pH. Cependant, une trop forte concentration encalcium (>50 ppm) causait une augmentation de mortalité dans certains cas. Les tetards de *Rana* clamitaus ainsi. Que les adults de *Notophthalmus viridescens* ont résisté à un exposition à un pH aussi faible que 3.3; cette tolerance était réduite à basse tempèrature.

Introduction

The impacts of acidic deposition on amphibians, compared with fish and forests, have received relatively little attention. However, amphibiansm may be susceptible to acidification, and are ecologically important in some forest/pond ecosystems (Burton and Likens 1975a; Wassersug 1975; Seale 1980).

In the United States 90% of frog and toad species and 50% of salamander species lay their eggs in water; many of these breed in ephemeral pools filled with rainwater or snowmelt, as opposed to groundwater (Pough and Wilson 1977). In regions receiving acidic deposition, breeding ponds may have pH similar to precipitation, especially during spring (Pough and Wilson 1977). Since many amphibians enter temporary ponds to breed in spring, the most susceptible stages of their life histories (reproduction and early embryonic development) may coincide with the most acidic breeding site conditions.

Several field studies have suggested that habitat acidity can reduce population size or restrict distribution of amphibians (reviewed recently in Dale et *al.* 1985). Various laboratory studies support these field observations, and also suggest physical and chemical mechanisms of amphibian reproductive failure. Schlichter (1981) reported

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Table I Chemistry of the water types used in laboratory bioassays

	pH	Conduct. (µmho-cm)	Color (Hazen Units)	Alkalinity (mg/l)	Na (mg/l)
dechlorinated[1] tapwater	7.8	21.0	0	86	3.4
clearwater[2] oligotrophic	5.5	0.0	5	24	2.6
brownwater[3] oligotrophic	4.6	0.0	80	33	2.7

[1] From Dalhousie University.
[2] From Beaverskin Lake, Kejimkujik National Park, Nova Scotia.
[3] From Pebbeloggitch Lake, in the Park.

that pH≤6.5 decreased sperm motility in the leopard frog (*Rana pipiens*), and that the number of healthy embryos decreased at pH ≤6.3. Several authors have found that low pH caused deformities or arrest of embryonic development. In recent reviews of laboratory experiments, the sensitivity of embryonic development to acidic media was found to be rather similar among 14 amphibian species (Tome and Pough 1982; Pierce 1985). In most cases pHs of 3.7 to 3.9 during development produced mortality >85%, and prolonged exposure to pHs <4.0 caused mortality >50%. Gosner and Black (1957) found that embryos were more sensitive than larvae, with some embryos showing ≥85% mortality at pH 4.0. Pough (1976) reported that high egg mortality of yellow-spotted salamanders (*Ambystoma maculatum*) seen in New York ponds with pH<6, was also observed under laboratory conditions. Furthermore, the mortality occurred at the same developmental stages: neurulation, late gill stage, and hatching. Deformities observed in the field were also seen in the laboratory, with swelling near the heart, stunted gills, failure of yolk plug retraction, and deformation of the posterior trunk. Pough (1976) also noted that at pH 4 embryos were tightly coiled within their membrane. This coiling was attributed to failure of expansion of the perivitelline space, which caused a mechanical constriction of the embryo leading to death or deformation (Gosner and Black 1957; Pough 1976; Pough and Wilson 1977). When yellow-spotted salamander embryos which failed to hatch at pH 4.0 were removed from the egg membrane, they were unable to swim or straighten their bodies (Pough and Wilson 1977). Working with the African clawed frog (*Xenopus laevis*), Dunson and Connell (1982) reported that removal of the membrane from embryos at pH 4.3 (which otherwise would not have hatched), allowed normal development.

Objectives of the present study were: i) to conduct laboratory experiments to determine the effect of low pH on embryonic and early larval development of selected native amphibian species, and the African clawed frog; ii) to examine the effect of two frequently-occurring types of Nova Scotian freshwaters (i.e. acidic clear and brown oligotrophic water) on reproductive success of selected native amphibians and the African clawed frog; iii) to examine effects of calcium and aluminum additions, in combination with pH and water type, on reproductive success of selected native species and the African clawed frog; and iv) to examine the effect of low pH on the ability of frog larvae (*Rana clamitans*) and adult newts (*Notophthalmus viridescens*) to survive at different temperatures.

K →	Ca	Mg	SO_4	Cl	Al	Total Organ. Carbon
0.40	13.0	0.10	8.5	n.d.	0.10	n.d.
0.20	0.4	0.34	2.6	4.3	0.04	5.6
0.20	0.3	0.33	3.3	4.4	0.16	17.2

Materials and Methods

Egg collection

Eggs of native species were collected in the field or from wild amplexed adults brought into the laboratory. Eggs collected in the field were transported to the laboratory in their natural water and maintained in a controlled environment at 12°C until used.

Eggs used in the *X. laevis* assays were collected from adults induced to breed by injection of human chorionic gonadotropin (Carolina Biological Supply Co., injection method no. 4, male - 250 I.U., female - 500 I.U.). Breeding pairs were maintained in a 30 L aquarium fitted with a false bottom with a removable glass tray. With this apparatus undisturbed eggs could be removed prior to first cleavage and selected for viability prior to use in experiments.

Eggs were added to treatment waters either as intact masses (*Ambystoma maculatum, Rana sylvatica, R. palustris*) or as groups of single eggs (*Xenopus laevis, Hyla crucifer, Bufo americanus*). *R. sylvatica, A. maculatum,* and *X. laevis* were staged according to Rugh (1962). *Rana clamitans* was staged according to Gosner (1960).

Water types

Polyethylene containers were filled with dechlorinated tap water, clear oligotrophic water, or brown oligotrophic water. The latter two were collected from Beaverskin Lake and Pebbleloggitch Lake, respectively, in Kejimkujik National Park (Kerekes *et al.* 1982). Chemical constituents of the three water types are summarized in Table I. One experiment used 10% frog Ringers, consisting of 11.5 mM NaCl, 0.2 mM KCl, 0.14 mM $CaCl_2$, and 0.24 mM $NaHCO_3$ (Schlichter 1981).

Buffers

Three of the six *X. laevis* assays were buffered to control pH drift. Following Schlichter (1981), buffered solutions were 25 millimolar and consisted of either sodium acetate/acetic acid ($pK_a = 4.8$), MES = 2 [N-Morpholino] ethanesulfonic Acid ($pK_a = 6.1$), or HEPES = N-2-Hydroxyethylpiperazine-N' -2- ethanesulfonic Acid ($pK_a = 7.5$).

pH adjustment

pH was adjusted using H_2SO_4 and NaOH, and was measured at the experimental temperature. pH $\leq$4.25 were stable over three or four days, but at higher pH drift towards neutrality occurred, by as much as 0.5 pH units per day in preliminary, aerated experiments. We therefore adjusted pH once or twice daily. In this manner, pH was maintained within 0.2 pH units of the desired value for experiments reported here. All assays had a complete change of treatment water at least once weekly.

Water in several of our earlier experiments was aerated. Since this practice caused greater pH drift, it was discontinued for experiments reported here, with no apparent ill effect on developing embryos or larvae.

Aluminum and calcium

In assays using aluminum, solutions were made by adding 1000 ppm Al stock solution (made from $AlCl_3\ 6H_20$), and then adjusting to desired pH. Calcium solutions were made by adding 10,000 ppm Ca stock solution (made from $CaCl_2\ \cdot 2H_20$). Concentrations of Al and Ca were measured by atomic absorption spectro photometry. Concentrations reported are total Al and Ca, and include back ground concentration in assay waters (see Table I).

Monitoring

Assays ran until hatching was completed, and in several cases well into the larval phase. These times ranged from 1 to 7 weeks. Observations of developmental and hatching success were made during these periods.

Upon termination, each assay was scored (where applicable) for % hatched, % hatched but later died, and % hatched but deformed.

Bioassays

Over 1982-83, bioassays were performed on 7 native species and *X. laevis*. Methods used for each are summarized below, ordered by species.

Ambystoma maculatum

pH - tapwater 12°C. Intact egg masses were placed in 3 L of dechlorinated tapwater adjusted to pHs 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, or 7.0 (3 replicates/treatment), and incubated at 12°C for 41 days. Embryos were initially at, or prior to, the fourth cleavage division (stage 5, Rugh 1962).

pH - tapwater 21°C. This assay was identical to the previous, except the incubation temperature was 21°C, and the assay ran for 35 days.

pH - clear and brown oligotrophic water. Intact *A. maculatum* masses prior to the blastula stage (stage 6, Rugh 1962) were incubated at 12°C for 41 days in 4 L of either clear or brown oligotrophic water. These waters had been adjusted to pH 3.5, 4.0, 4.5, or 5.0, with 2 replicates/treatment.

Calcium - pH interactions. This assay was a 5 x 5 matrix of pH and calcium, with one replicate/treatment. Egg masses were divided into portions of 9-24 embryos, randomly assigned to treatment, and incubated at 21°C in 300 ml of dechlorinated tapwater adjusted to a particular pH and calcium concentration. pHs were 3.5, 4.0, 4.5, 5.0, and 6.0, and calcium concentrations were 10, 30, 50, 70, and 90 ppm. Embryos were initially at the late blastula stage (stage 9, Rugh 1962). The assay ran for 27 days.

Aluminum - pH interactions. This assay was a 4 x 5 matrix of aluminum and pH, with 2 replicates/treatment. pHs were 3.5, 4.0, 4.5, 5.0, and 6.0, and total aluminum concentrations were 0.1, 0.4, 0.7, and 1.1 ppm. Egg masses were divided (range of 18-46 eggs/treatment), randomly assigned to treatment, and incubated at 21°C in 3 L of dechlorinated tapwater for 31 days. Embryos were initially at the late blastula stage (stage 9, Rugh 1962).

Hyla crucifer

pH - tapwater. Containers with 300 ml of dechlorinated tap water were adjusted to one of the following pHs: 3.0, 4.0, 5.0, 6.0, 7.0, or 8.0. Eggs were obtained in the laboratory from an amplexed pair of wild adults; There were 35 eggs (midblastula stage) per treatment. Assays were maintained at 20°C for 18 days.

pH - aluminum. This assay was a 5 x 4 matrix of pH and aluminum. pHs were 3.5, 4.0, 4.5, 5.0, and 6.0, and aluminum concentrations were 0.1, 0.4, 0.7 and 1.1 ppm. Two replicates per treatment (range 11 to 34 midblastula eggs) were incubated at 21°C in 100 ml of dechlorinated tapwater solution, for 16 days.

Rana sylvatica

pH - tapwater 12°C. Portions of egg masses were placed in containers with 3 L of dechlorinated tapwater adjusted to pH 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, or 7.0 (2 replicates/treatment), and incubated at 12°C for 18 days. Embryos were initially at, or prior to, the fourth cleavage division (stage 6, Rugh 1962).

pH - tapwater 21°C. This experiment was identical to the previous, except the incubation temperature was 21°C, and the assay ran for 11 days.

pH - clear and brown oligotrophic water. This bioassay involved intact egg masses at 12°C in clear or brown oligotrophic water. Four liter solutions were adjusted to pH 3.5, 4.0, 4.5, or 5.0, with 2 replicates/treatment. Embryos were initially at, or prior to, the fourth cleavage division (stage 6, Rugh 1962). The assay ran for 19 days.

Calcium - pH interactions. This bioassay was a 5 x 5 matrix of pH and calcium. Egg masses were divided into portions with 25-75 embryos, randomly assigned to treatment, and incubated at 21°C in 300 ml of dechlorinated tapwater adjusted to pH 3.5, 4.0, 4.5, 5.0, or 6.0, and/or calcium concentration of 10, 30, 50, 70, or 90 ppm. Embryos were initially at the gastrula stage (stage 12, Rugh 1962). The assay ran for 7 days.

Rana palustris

A single egg mass of *R: palustris* was divided into portions (37 to 62 eggs/treatment) and incubated for 26 days in 300 ml of 12°C dechlorinated tapwater adjusted to pH 3.0, 3.5, 3.8, 4.0, 4.3, 4.5, 5.0, 6.0, or 7.0. Embryos were at or before the 32 cell stage. There were 2 replicates/treatment, and the experiment ran for 26 days.

Bufo americanus

pH - tapwater - 21°C. This assay involved incubating groups of eggs at the early gastrula stage (46-51 eggs/treatment) in 3 L of 21°C dechlorinated tapwater adjusted to pH 3.0, 3.5, 3.75, 4.0, 4.25, 4.5, 5.0, or 6.0. The assay ran for 11 days, with 2 replicates per treatment.

Calcium - pH interactions. This assay was a 5 x 5 matrix of pH and calcium. pHs were 3.5, 4.0, 4.5, 5.0, or 6.0, and calcium concentrations were 10, 43, 76, 110, or 210 ppm. Groups of eggs at the gastrula stage (range 23-28 eggs per treatment) were incubated at 21°C in 300 ml of dechlorinated tapwater for 10 days, with 2 replicates per treatment.

Aluminum - pH interactions. This assay was a 5 x 6 matrix of pH and aluminum. pH was 3.5, 4.0, 4.5, 5.0, or 6.0, and aluminum concentration was 0.10, 0.60, 0.85, 1.10, 1.60, or 2.10 ppm. Groups of eggs at the early gastrula stage (47-52 eggs/treatment) were incubated at 21°C in 2 L of dechlorinated tapwater for 11 days, with 2 replicates per treatment.

Rana clamitans

Effect of temperature and pH on larvae. First-year larvae (stage 25 to 29, Gosner 1960) were assayed either at 5°C or 21°C. Larvae were collected in the field on 9 October, 1983 at a field pH of 6.4 and temperature of 13°C. Larvae were placed in 12°C aerated dechlorinated tapwater, and over the next month temperature was gradually reduced to 5°C. During this acclimation period larvae were fed boiled lettuce. For the 5°C assay, containers with 2 L of dechlorinated tap water were adjusted to the following pHs: 3.5, 3.8, 4.0, 4.3, 4.5, 5.0, or 6.0. There were 3 replicates per treatment, and 10 larvae per replicate. The experiment ran for 38 days.

For the 21°C assay larvae were gradually acclimated over 2 weeks to 21°C. The assay ran for 13 days, and was identical to the 5°C assay except for temperature, addition of pH 3.3 and 7.0 treatments, and deletion of pH 4.3.

Notophthalmus viridescens

Effect of temperature and pH on adults. Adult newts were assayed at 5°C and 21°C. Newts were collected in the field on 9 October, 1982 at a field pH of 6.2 and temperature of 12°C. They were kept in the laboratory in 12°C aerated dechlorinated tap water, and over the next month water temperature was gradually reduced to 5°C. During this acclimation period newts were fed raw beef liver. For the 5°C assay, containers with 2 L of dechlorinated tap water were adjusted to the following pHs: 3.5, 3.8, 4.0, 4.3, 4.5, or 5.0. There were 3 replicates per treatment, and 10 newts per replicate. The experiment ran for 38 days. For the 21°C assay newts were gradually acclimated over a 2-week period to 21°C. The assay ran for 13 days, and was identical to the 5°C assay except for temperature.

Xenopus laevis

Buffered/unbuffered - sodium acetate/acetic acid. Fourteen containers were prepared, each containing 300 ml of dechlorinated tap water. Seven of the containers were acidified using 25 mM sodium acetate/acetic acid as a buffer ($pK^a = 4.8$), following Schlichter (1981). The remaining containers did not have buffer added. The 7 pairs of acetate or non-acetate treatments were adjusted to the following pHs: 4.0, 4.5, 4.8, 5.0, 5.3, 5.5, or 6.0. Twelve eggs (prior to the eight cell stage, stage 5, Rugh 1962) were placed in each container. Assays were maintained at 21°C for 6 days.

A parallel assay was run to confirm observations made in the above experiment. Groups of 10 eggs (four cell stage, stage 4, Rugh 1962) were incubated at 21°C in 800 ml of 10% amphibian Ringers solution adjusted to pH 3.5, 4.0, 4.5, 5.0, 6.0, or 7.0. These solutions were either unbuffered or buffered with sodium acetate/acetic acid at a concentration of 25 mM. There were 2 replicates/treatment, and the experiment ran for 5 days.

Aluminum - pH interactions. Clear and brown oligotrophic waters were used in this assay. For each water type a 6 x 6 matrix of pH and aluminum concentration was established, with pH of 3.0, 3.5, 4.0, 4.5, 5.0, or 6.0, and aluminum concentration of 0.05 to 1.15 ppm. Microliter amounts of a 1000 ppm aluminum solution were pipetted into 100 mL of water to give desired aluminum concentrations.

Solutions were then adjusted to desired pH. Ten eggs (prior to the four cell stage, stage 3, Rugh 1962) were placed into each beaker. Assays were maintained at 21°C for 11 days.

Calcium - pH interactions. This assay was identical to the aluminum assay described above, except that: i) the matrix was 5 x 5 with pH 3.0, 3.5, 4.0, 4.5, or 5.0 and calcium concentration of 0, 20, 40, 60, or 80 ppm; ii) a 10,000 calcium solution was used; and iii) the assay ran for 10 days.

Table II *Ambystoma maculatum* bioassays in dechlorinated tapwater

	12°C		21°C	
pH	No. of eggs in mass	% hatched	No. of eggs in mass	% hatched
7.0	48	23	54	43
	52	52	47	51
6.0	86	6	62	40
	85	26	42	81
5.0	67	40	75	32
	57	11	76	46
4.5	56	2	118	2
	111	9	56	11
4.0	62	0	72	0
	42	0	83	1
3.5	>50	0	>50	0
	>50	0	>50	0
3.0	>50	0	>50	0
	>50	0	>50	0

Results

Ambystoma maculatum

pH effects at 12°C. No hatching or development of embryos were observed at pH 3.0 or 3.5 (Table II). At these pHs, the gelatinous mass that contained the eggs turned a milky-opaque colour within 2 hours of exposure, and the egg mass subsequently shrank in volume, becoming rubbery in texture.

At pH 4.0 egg masses turned slightly opaque; nevertheless embryos appeared to be developing normally. However, after 20 days of incubation all embryos were dead. At pH 4.5 embryos were tightly coiled within the perivitelline space. The 6% that did hatch were deformed with abnormal body curvatures (both scoliosis and kyphosis: effects on spinal development). Deformed larvae were observed using the double-staining technique of Hanken and Wassersug (1981), and indicated that fusion of some vertebrae had occurred; this may have caused the abnormal spinal curvatures.

At pH 4.5 only 6% of embryos hatched successfully, although unhatched developing embryos had appeared normal. Hatching success improved somewhat at pHs 5.0, 6.0, and 7.0 with 26%, 16%, and 38%, respectively. These latter percentages were less than obtained in preliminary experiments run one year previously at the same pHs but at 15°C (mean hatching success of 93%). This probably reflects some inherent inviability of the egg masses used in the 1983 experiments. Larger experiments with greater replication would have been desirable for documenting interspecific variation in viability; however experiments of such scope would have been difficult logistically, and were beyond our means.

pH effects at 21°C. No hatching or development were observed at pH 3.0 or 3.5 (Table II). At pH 4.0 one deformed embryo hatched, but it soon died. Unhatched embryos at pH 4.0 developed to the head/tail stage (stage 25, Rugh 1962). They were all tightly coiled within the vitelline membrane and died without hatching.

At pH 4.5 development was slow, compared to higher pHs, and many embryos died at an early stage. Seven percent of these embryos hatched. These were initially scoliotic, but at the end of the experiment they appeared normal and were able to swim. At higher pHs hatching success was improved.

Brown vs. clear oligotrophic water. This experiment, run at 12°C, did not indicate any differences in pH toxicity between the two water types. No hatching occurred at pH 3.5 or 4.0, while at pH 4.5 and 5.0 hatching averaged (n=2) 36% in the clear, and 30% in the brown oligotrophic water.

Calcium - pH interactions. Results of this experiment indicate that with calcium concentrations of at least 30 ppm at pH 4.0, hatching occurred (21% at 30 ppm calcium, 20% at 50 ppm, 8% at 70 ppm, 4% at 90 ppm), while none occurred at 10 ppm calcium. At pH >4.5, hatching success was high (overall mean of 15 treatments was 90%) at all calcium concentrations.

Aluminum - pH interactions. From pHs 4.5 to 6.0 aluminum had no effects on hatching success. However, at pH 4.0 mean (n=2) hatching success was decreased from 11% at 0.1 ppm total aluminum, to 3% at 0.4 ppm, and 2% at both 0.7 and 1.1 ppm. However, all larvae hatched at pH 4.0 died over the following few days.

Table III *Hyla crucifer* bioassay at 20°C in dechlorinated tapwater

pH	% hatched[1]	% hatched, but later died
8.0	83	0
7.0	80	0
6.0	80	0
5.0	77	11
4.0	54	100
3.0	0	-

[1] Of 35 individual eggs.

Hyla crucifer

pH effects. No hatching or development were observed at pH 3.0 (Table III). The gelatinous sheath around individual eggs (this species does not lay egg masses) was compressed in volume at pH 3.0 by a factor of ca. 1/2, and by a lesser degree at pH 4.0. However, the gelatin did not turn opaque.

At pH 4.0, hatching success was 54%, but all hatched larvae subsequently died. At this pH, developing embryos were tightly coiled within a compressed perivitelline space; head and tail of the embryos overlapped, for a total coiling of about 430 degrees of arc, compared with about 280 degrees at higher pH. All hatched larvae at pH 4.0 were deformed with gross body curvatures, were incapable of swimming, and all subsequently died.

At pH ≥5.0 hatching success averaged 80%, but there was higher mortality among hatched larvae at pH 5.0 (11% versus <1% over pH 6 to 8). Twenty percent of hatched larvae at pH 5.0 had body curvature deformities and impaired swimming.

Aluminum - pH interactions. There was no consistent effect of aluminum on hatching success of *H. crucifer* at any of the pHs where hatching occurred (i.e. pHs

Table IV *Rana sylvatica* bioassays in dechlorinated tapwater

pH	12°C No. of eggs in mass	12°C % hatched	21°C No. of eggs in mass	21°C % hatched
7.0	451	92	473	92
	409	95	213	98
6.0	333	51	378	77
	318	46	346	80
5.0	473	51	262	97
	357	39	319	90
4.5	340	38	337	95
	296	40	323	82
4.0	320	17	119	8
	313	6	276	<1
3.5	>200	0	>200	0
	>200	0	>200	0
3.0	>200	0	>200	0
	>200	0	>200	0

4.5, 5.0, and 6.0). No hatching occurred at pH 4.0, contrary to results presented in the previous section, which indicated a hatching success of 54%, although all of these hatched larvae soon died.

Rana sylvatica

pH effects at 12°C. No hatching or development were observed at pH 3.0 (Table IV). At this pH the gelatinous mass that contained the eggs turned a milky-opaque colour within 2 hours of first exposure. Overall volume of the egg mass subsequently shrank, and it became rubbery in texture over the next few days, ending up as a small, tight, spherical structure. At pH 3.5 some embryos developed to the neural plate stage (stage 14, Rugh 1962) before being aborted. Otherwise, these egg masses were similar to those at pH 3.0.

Over the pH range 4.0 to 7.0 hatching occurred. At pH 4.0 12% of the embryos hatched compared with an average of 44% over pH 4.5 to 6.0, and 94% at pH 7.0. pH 4.0 embryos were tightly coiled within the vitelline membrane, and the few that did hatch subsequently died.

pH effects at 21°C. No hatching or development occurred at pH 3.0 (Table IV). Four pH 3.5 embryos developed to the head/tail stage (stage 18, Rugh 1962), and muscular movement was detected; however, none of these hatched. An average of 50% of pH 4.5 to 7.0 embryos had hatched before any pH 4.0 embryos hatched, and when 90% of the former had hatched, only 4% of the pH 4.0 embryos had hatched. The latter hatched larvae were maintained at pH 4.0 for 30 days, after which they appeared normal in swimming and feeding behavior, compared with controls. Unhatched pH 4.0 embryos were all tighly coiled with >360° of arc.

Brown vs. clear oligotrophic water. This experiment did not indicate differences in pH toxicity between the two water types. No hatching occurred at pH 3.5, while at pH 4.0, 4.5, and 5.0 hatching averaged 52%, 84%, and 90% in the clear water, and 43%, 87%, and 93% in the brown water.

Table V *Rana palustris* bioassays at 12°C in dechlorinated tapwater

pH	No. of eggs[1]	% hatched	% hatched that later died
7.0	43	100	0
	37	100	0
6.0	41	100	0
	53	100	0
5.0	49	41	50
	22	36	50
4.5	40	5	50
	44	5	50
4.3	39	0	-
	48	0	-
4.0	62	0	-
	41	0	-
3.8	53	0	-
	52	0	-
3.5	55	0	-
	38	0	-
3.0	50	0	-
	43	0	-

[1] Excized from a single egg mass.

Table VI *Bufo americanus* bioassays at 21°C in dechlorinated tapwater

pH	No. of eggs[1]	% hatched
6.0	50	100
	51	100
5.0	50	100
	50	100
4.5	48	100
	46	100
4.3	50	100
	49	82
4.0	50	84
	50	96
3.8	50	0
	49	0
3.5	48	0
	49	0
3.0	47	0
	51	0

[1] Groups from a single egg strand.

Calcium - pH interactions. No embryos hatched at pH 3.5 or 4.0, though many developed to the stage where external gills were present (stage 19, Rugh 1962).

At pH 4.5 hatching success decreased with increasing calcium concentration (100% at 10 ppm calcium, 71% at 30 ppm, 41% at 50 ppm, 11% at 70 ppm, and 20% at 90 ppm). This effect did not occur at either pH 5.0 or 6.0, with hatching success uniformly >90% (mean of 10 observations = 94%).

Rana palustris

pH - tapwater. Hatching was reduced from 100% at pH 6.0 to 39% and 5% at pHs 5.0 and 4.5, respectively (Table V). At pH <4.5 no hatching occurred. Larvae hatched at pH 5.0 or 4.5 were deformed and could not swim properly; some died soon after hatching.

Bufo americanus

pH - tapwater. Hatching success ranged from 90% to 100% over pH 4.0 to 6.0 (Table VI). However, at pH <4.0 no hatching occurred. All embryos at pH <3.8 failed to develop, the gelatin coat surrounding each embryo became opaque, and embryos

Table VII *Rana clamitans* bioassays for larvae in dechlorinated tapwater

pH	% survival[1] after 38 days at 5°C	% survival after 14 days at 21°C
7.0	-	100 100 100
6.0	40 20 60	100 100 100
5.0	80 80 80	100 100 100
4.5	80 90 60	100 100 100
4.3	50 90 80	-
4.0	50 90 80	100 100 100
3.8	60 90 70	100 100 100
3.5	30 60 60	100 100 100
3.3	-	50 0 0

[1] Of 10 larvae in each replicate.

appeared to be touching each other, indicating failure of formation of the perivitelline space.

Calcium - pH interactions. This experiment demonstrated no effect of calcium on hatching success. Hatching success was >90% at all pHs and calcium concentrations from pH 4.0 to 6.0 (mean = 97%). No hatching occurred at pH 3.5.

Aluminum - pH interactions. As above, hatching was >90% at all pHs and total aluminum concentrations from pH 4.0 to 6.0 (mean = 96%), and no hatching occurred at pH 3.5.

Rana clamitans

Effect of temperature on pH tolerance. At 5°C, survival was <100% at all pHs, with lowest survival at pH 3.5 and 6.0 (Table VII). At 21°C, survival was lowest at pH 3.3 (averaging 17%), and was 100% at all higher pHs. Thus, cooler bioassay temperature negatively affected survival at all pHs. Nevertheless, many larvae survived relatively low pH (i.e, <4.0), in contrast to our observations of toxicity to embryonic and early larval development in other species.

Notophthalmus viridescens

Effect of temperature on pH tolerance. At 5°C, survival averaged 20% at pH 3.5, and 100% at all higher pHs (Table VIII). At 21°C, survival averaged 71% at pH 3.5, and was essentially 100% at all higher pHs. Thus, cooler temperatures predisposed adult newts to death at the lowest pH used in this bioassay.

Xenopus laevis

Buffered vs. unbuffered assay solutions. Effects of buffering with acetate on hatching success were quite clear. Embryos in unbuffered solutions hatched at pH ≥4.5 (Table IX). Embryos in acetate-buffered solutions did not hatch at pH <6. In the buffered solutions, embryonic development did not occur over pH 4.0 to 5.0; some development occurred at pH 5.3 and 5.5, but this was arrested at the 128-cell stage (stage 7, Rugh 1962). These observations were consistent in two separate experiments - one run in dechlorinated tapwater, and the other in amphibian Ringers solution.

Aluminum - pH - water type interactions. In neither brown nor clear water was hatching or development observed over the pH range 3.0 to 4.0 (Table X). In the brown water, hatching success was little affected by either pH from 4.5 to 6.0, or aluminum from 0.15 to 1.15 ppm. However, survival of hatched larvae was lower at the highest aluminum concentrations (especially at pHs 4.5 and 5.0; the effect was less at pH 6.0), although there were several anomalous results (e.g. at pH 4.5 and with 0.15 ppm aluminum).

Similar observations were made for hatching in the clear water from pH 4.5 to 6.0, apart from lower hatching at pH 5.0 with higher aluminum concentrations. Again, survival of hatched larvae was impaired at higher aluminum concentrations at pHs of 4.5 and 5.0, but not at pH 6.0. Differences in hatching or survival between the two water types were not consistent.

At 0.05 to 0.15 ppm aluminum, a high frequency of deformed larvae (body curvature) was found at pH 4.5, especially in the brown water. At more moderate pH (e.g. pH >5.0) but high aluminum concentration (e.g. >0.55), malformed larvae also occurred. Albinism and incomplete yolk sac absorption were frequent.

Calcium - pH - water type interactions.

No hatching occurred in either water type at pH 3.0 or 3.5 (Table XI). Hatching also did not occur at pH 4.0 with calcium concentrations of 0 to 40 ppm, but this effect was ameliorated at higher calcium concentrations. Similarly, pH 4.5 showed a toxic effect

Table VIII *Notophthalmus viridescens* bioassays for adult animals in dechlorinated tapwater

pH	% survival[1] after 38 days at 5°C	% survival after 14 days at 21°C
5.0	100	100
	100	100
	100	100
4.5	100	87
	100	100
	100	100
4.3	100	100
	100	100
	100	100
4.0	100	100
	100	100
	100	100
3.8	100	100
	100	100
	100	100
3.5	10	75
	20	87
	30	50

[1] Of 10 adults in each replicate.

Table IX *Xenopus laevis* bioassays in dechlorinated tapwater or amphibian Ringer's solution

pH	% hatched[1] in dechlorinated tapwater, 21°C		% hatched[2] in 10% amphibian Ringer's, 21°C	
	buffered[3]	unbuffered	buffered[3]	unbuffered
7.0	-	-	50	90
			0	50
6.0	17	58	0	100
			0	40
5.5	0	50	-	-
5.3	0	58	-	-
5.0	0	75	0	20
			0	90
4.8	0	42	-	-
4.5	0	67	0	40
			0	90
4.0	0	0	0	0
			0	0
3.5	-	-	0	0
			0	0

[1] Of 12 individual eggs per treatment.
[2] Of 10 eggs per replicate per treatment.
[3] Buffered with 25 millimolar sodium acetate/acetic acid.

Table X *Xenopus laevis* bioassays for interaction of pH and aluminum

	pH	Aluminum Concentration (ppm)					
		0.15	0.20	0.40	0.65	0.90	1.15
a) Brownwater oligotrophic	3.0	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	3.5	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	4.0	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	4.5	88(100)[1]	100(38)	100(0)	100(0)	100(100)	100(100)
	5.0	100(0)	100(0)	100(0)	100(0)	90(100)	100(100)
	6.0	100(0)	100(0)	100(0)	100(0)	100(50)	100(40)
		0.05	0.10	0.30	0.55	0.80	1.05
b) clearwater oligotrophic	3.0	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	3.5	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	4.0	0(-)	0(-)	0(-)	0(-)	0(-)	0(-)
	4.5	100(0)	80(0)	86(0)	100(100)	100(100)	100(100)
	5.0	100(0)	100(0)	100(20)	80(100)	33(100)	20(100)
	6.0	100(0)	100(0)	100(14)	100(0)	100(0)	100(0)

[1] % hatching at 21°C (of 10 eggs, 70% proving to be fertilized and viable) followed by % dead of hatched larvae at end of experiment, in parentheses.

Table XI *Xenopus laevis* bioassay for interaction of pH and calcium

	pH	Calcium Concentration (ppm) 0	20	40	60	80
a) Brownwater oligotrophic	3.0	0(-)	0(-)	0(-)	0(-)	0(-)
	3.5	0(-)	0(-)	0(-)	0(-)	0(-)
	4.0	0(-)	0(-)	0(-)	9(100)	40(100)
	4.5	0(-)	40(100)	50(0)	91(0)	55(0)
	5.0	55(100)[1]	55(100)	80(0)	90(0)	60(0)
b) clearwater oligotrophic	3.0	0(-)	0(-)	0(-)	0(-)	0(-)
	3.5	0(-)	0(-)	0(-)	0(-)	0(-)
	4.0	0(-)	0(-)	0(-)	75(100)	78(100)
	4.5	10(0)	100(0)	90(0)	80(0)	90(0)
	5.0	80(0)	80(0)	70(0)	90(0)	90(0)

[1] Conditions as in footnote 1, Table X.

at 0 ppm calcium, but this was ameliorated at higher calcium concentrations. Thus, calcium clearly ameliorated pH toxicity in this species, but this only occurred at relatively high calcium concentrations.

Discussion

Acidity

All organisms have a physiological tolerance range for environmental variables, outside which they cannot survive. This is true for amphibians with regard to pH. Our bioassays were designed to determine the lower limit of pH tolerance for certain amphibian species, and they focussed mainly on the most susceptible life history stage. No hatching occurred below pH 4.0 (i.e. at pH 3.8), for any Nova Scotian amphibians tested. However, among the five native species assayed, some were more sensitive to moderate pH than others, as discussed below.

Ambystoma maculatum suffered a drastic reduction in hatching success at pH ≤4.5 (Table II). Similar results have been reported for both laboratory (Pough and Wilson 1977) and field studies (Pough 1976).

Hatching success of *Hyla crucifer* was not impaired at pH ≥4.5, although subsequent survival was reduced even at pH 5.0 (Table III), and some larvae were deformed. Gosner and Black (1957) reported the only comparable data for this species. They found that pH 4.2 allowed only 50% hatching, and that pH 3.8 was lethal.

Hatching of *Rana sylvatica* was relatively unaffected at pH ≥4.5 (Table IV). At pH 4.0 hatching success was greatly reduced, and developmental abnormalities occurred. At pH 3.5 embryonic development was arrested. Both Gosner and Black (1957) and Pierce *et al.* (1984) reported similar findings for this species; they found 50% hatching at pH 3.9 and 3.75, respectively, and no development at pH 3.5. In contrast, Tome and Pough (1982) reported 90% hatching at pH 4.0 and >50% at pH 3.5.

A drastic reduction in hatching success of *Rana palustris* occurred at pH <5.0 (Table V). The only other study on this species (Gosner and Black 1957) found pH 4.3 to be the "minimum limiting pH value", where >50% hatching occurred. Their data indicate a greater tolerance of low pH by this species, than do our observations. Gosner and Black (1957) worked with animals collected from or near acidic bog waters in New Jersey. Animals from that area may have evolved acid tolerance, but if not they at least represent a different population from animals collected in Nova Scotia. Other researchers have hypothesized that local populations of amphibians may have evolved tolerance to low pH (Gosner and Black 1957; Tome and Pough 1982; Cook 1983), but to date no experimental evidence exists to support this.

Bufo americanus may be the most tolerant of the Nova Scotian species assayed. Hatching success was 100% at pH ≥4.0 (Table VI). However, at pH 3.8 there was no hatching. There are no comparitive data in the literature for this species.

Xenopus laevis had variable hatching success at pH ≥4.5, ranging from 0 to 100% at pH ≥4.5 and from 50 to 100% at pH 5.0, depending on the assay (Tables IX-XI). However, no hatching occurred at pH ≤4.0. These results agree with those of Saber and Dunson (1978) and Dunson and Connell (1982), where pH 3.9 was lethal. However, Tome and Pough (1982) found no significant differences in hatching success from pH 4.0 to 9.0 (60-70% hatching success), and even at pH 3.5 they had 30-40% hatching. Their results indicate greater tolerance of low pH, than shown by other studies.

In summary, amphibian species vary in susceptibility to acidity in laboratory assays. Some such as *B. americanus,* tolerate relatively extreme conditions. Others such as *R. palustris,* are less tolerant.

Aluminum

In no aluminum bioassays were there discernable effects of aluminum; hatching seemed to only be affected by acidity of the water. However, in the *X. laevis* assay, aluminum did have an effect on deformities and post-hatching mortality (Table X). One other study has investigated effects of aluminum on amphibian reproduction. Clark and Hall (unpublished) found that hatching successes in the field of *B. americanus, R. sylvatica,* and *A. maculatum* were highly negatively correlated with total Al, inorganic monomeric Al, total AlF complexes, Al^{3}Ø, and acidity.

Calcium

Addition of calcium to the assay medium, in an attempt to ameliorate effect of pH, had variable results, depending on the amphibian species being assayed. Acid tolerance of *B. americanus* was unaffected by calcium. *A. maculatum* exhibited a weak positive effect, while *R. sylvatica* suffered reduced hatching with the addition of calcium. *X. laevis* was the only species which clearly benefitted from calcium. The addition of 60 to 80 ppm calcium at pH 4.0 allowed hatching at this pH, which was otherwise lethal (Table XI). Freda and Dunson (1984) partially elucidated the reason for calcium's effect. Acute exposure of amphibian larvae to low pH (2.5 to 4.0) was found to depress sodium influx while markedly accelerating its efflux. The resulting net loss of 50% of body sodium was fatal. They found that an increase in external calcium concentration (from 0 to 200 ppm) extended survival time by slowing loss of sodium. However, since only four sites sampled in our parallel field studies (Dale *et al.* 1985) had calcium concentrations of >60 ppm (and these were all high-pH sites), the positive effect of calcium on survival of larvae in acidic situations is probably not an important factor for Nova Scotia amphibians.

Brownwater versus clearwater oligotrophic

In no bioassays were there clear differences between clear and brown oligotrophic water. In one assay that tested aluminum against the two water types using *X. laevis,* there was also no effect. Of interest in this latter experiment was the possibility that aluminum would be less toxic in the brown water due to chelation by organic compounds (Baker and Schofield 1982). A decreased toxicity was not observed.

Other researchers have investigated direct effects of brown water on amphibian reproductive success, in both the field and laboratory (Gosner and Black 1957; Saber and Dunson 1978; Hagstrom 1980). These studies have revealed that brown waters are toxic in themselves to developing amphibians. However, cause of the toxicity is not clear; low pH of these waters, toxic organic compounds such as fulvic acids (Saber and Dunson 1978), or metals may be responsible.

Buffers

We initially used buffered assay solutions to eliminate pH drift during exposure periods, following the procedure of Schlichter (1981). However, it is obvious that the sodium acetate/acetic acid buffer system is toxic to *X. laevis* (Table IX), and it should not be used in pH bioassays with this or other amphibian species. This acetate-toxicity effect probably explains toxic effects observed by Schlichter (1981) at relatively high pH, in acetate-buffered solutions using *Rana pipiens*.

Deformities

For all assays starting with early stage embryos, deformities resulting from low pH were similar to those described elsewhere for similar species (Gosner and Black 1957; Pough 1976; Pough and Wilson 1977; Dunson and Connell 1982). The most obvious deformation was curvature of the spine, either scoliosis or kyphosis, possibly caused by mechanical constriction of the embryo within the vitelline membrane. The causal mechanism for this constriction has been discussed by other researchers; it appears to involve decreased ability to uptake water, effectively preventing formation of the perivitelline space. It is also possible that hatching is prevented by inactivation of hatching enzymes, which are pH sensitive (Gosner and Black 1957; Dunson and Connell 1982). In many cases curvature that we observed carried over to the larval stage, resulting in an inability to swim properly, which would lead to an obvious and drastic decrease in fitness. Ossification of vertebrae in such a situation, resulting in fusion of neighboring vertebrae, would permanently handicap the organism. Unfortunately, larvae with this defect were not followed through metamorphosis, and it is not known how (or if) this defect would manifest itself in adults.

Temperature

Although the effect of incubation temperature on pH tolerance of developing embryos (*A. maculatum* and *R. sylvatica*; Tables II and IV) was assayed, the results were not conclusive. Other researchers have addressed this question more directly (Pough and Wilson 1977; Tome and Pough 1982). It does appear that very low water temperature in combination with low water pH reduces survival of amphibians. Both *R. clamitans* larvae and *N. viridescens* adults experienced increased mortality at 5°C compared to 21°C (Tables VII and VIII). This increased sensitivity to pH at low temperature, may indicate that larvae or adults which overwinter in water or are present during spring thaw may be at greater risk than species which do not follow this strategy, although it is not known what temperature and pH range this latter group (i.e. terrestrial hibernators) experiences.

Implications of Acidification

In some regions receiving acidic deposition, the pH of small, ephemeral water bodies can be similar to that of local precipitation (Pough and Wilson 1977). Unlike larger, more permanent bodies of water, these small ponds or pools can be created quickly by accumulation of rain or snowmelt. Frequently, these pools have little or no capacity to buffer or dilute incoming acid: i) owing to their small catchments, runoff is not in contact with soil long or intimately enough to significantly raise pH; ii) in early spring, deciduous foliage has not yet been produced, and rainwater acidity is not decreased by contact with leaves or stems (Prager and Freedman 1984); and iii) the ground may still be frozen, preventing runoff from percolating through soils and contacting neutralizing agents. Also, snow packs which have accumulated throughout the winter, tend to concentrate acidic substances near surfaces of snow crystals, so that initial meltwater is relatively concentrated with acid (Arland *et al.* 1980). Finally, it is early spring rains, or warm periods when spring thaw begins, that cue early spring breeders to enter ponds. Therefore, the most susceptible stages of many amphibian life histories (early embryonic and larval development), coincide with the most acidic breeding site conditions.

The implication of the preceeding discussion is that amphibians may suffer reproductive failure if breeding habitats become too acidic. The disappearance of amphibian populations could have detrimental effects on trophic relations in the ecosystem involved. Studies of hardwood forests at Hubbard Brook in New Hampshire revealed that salamanders were the largest and highest quality vertebrate food resource available to tertiary consumers such as birds, reptiles, or mammals (Burton and Likens 1975a, 1975b), some of which are known to prey heavily upon amphibians at least occasionally (Debenedictis 1974; Arnold and Wassersug 1978; Cecil and Just 1979; Racey and Euler 1983). In addition, amphibians appear at breeding sites in spring, coinciding with a period of low food availability for some vertebrate predators (Gerrell 1969). Amphibians are also important as top predators or primary consumers in fishless forest ponds (Dodson and Dodson 1971; Orser and Shure 1972; Seale 1980).

Relation to Field Observations

For all the native amphibian species that we assayed, the pH range of 4-5 is critical; within this range developing embryos suffer reduced hatching success, and below it hatching does not occur. It may be important then, that the mean annual pH of rain falling in Nova Scotia over 1977-1980 was 4.5-4.6 (Underwood 1982; Anonymous 1983). Under this loading, typical clearwater oligotrophic waterbodies in Nova Scotia currently have pH >5.0, while typical coloured humic waters have pH of ca. 4.5-5.0 due to the presence of naturally acidifying organic acids (Kerekes *et al.* 1982). Thus, for coloured waters particularly, the possibility exists that some disruption of amphibian breeding may occur, and this could increase if more widespread or more intense acidification of otherwise suitable habitats were to occur in the future.

We should note, however, that some of our field observations (Dale *et al.* 1984) indicate a somewhat greater tolerance of acidity by some species, than might be expected from some of our laboratory bioassays. For example, we observed successful hatching of *A. maculatum* and *R. sylvatica* in the field at a pH of 4.1, and *R. clamitans* larvae were collected in an extremely acidic (but eutrophic) lake with a mean pH of 4.0 (minimum pH of 3.8), and from an acidic ditch with a pH of 3.9 (Dale *et al.* 1984; Kerekes *et al.* 1984). These field observations indicate a rather high degree of acid tolerance in these species.

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DETERIORATION OF MATERIALS IN A QUARTER-MEGAWATT STRAWBURNER[1]

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An outline is given of the deterioration of refractories and stainless steels during the operation of a large strawburning furnace. The deterioration was caused by high temperatures, which sometimes exceeded 1400°C, and by a corrosive slagged ash. The use of different materials in alleviating these problems is described. Laboratory experiments on the corrosion of metals by straw slag are discussed, including work to determine the influence of chloride on the extent of corrosion.

Les caractéristiques genérale de la détérioration des matériaux réfractaires et de l'acier inoxydable pendant l'operation d'un incinérateur à paille sont décrites. La détérioration fut causée par les températures élevées qui depassaient parfois 1400°C et par l'effet corrosif des résidus de combustion. Certains materiaux sont susceptibles de corriger ces problèmes. Nous discutons des résultats obtenus en laboratoire de l'effet corrosif des cendres de paille sur certains metaux incluant l'influence du chlore.

Introduction

The energy crisis of the 1970's led to efforts to bring a wide variety of alternate energy sources first to the stage of demonstration and then into commercial production. One such effort was that of Lyndhurst Farms of Canning, N.S., which successfully demonstrated the large scale combustion of straw for drying grain and corn, and for space heating. Over several years the combustor was the subject of a good deal of developmental research sponsored by Agriculture Canada, the National Research Council, and Lyndhurst Farms. During that time a sequence of alterations radically altered its design. The alterations were principally the result of dealing with the deterioration of materials caused by high temperatures and corrosive slags. With the current hiatus in the perception of oil as a scarce commodity, and with laboratory studies having been performed on the attack of straw slags on stainless steels, it seemed an appropriate time to record some of the features of this unique Nova Scotian development.

The calorific value of average straw of moisture content 14% is 14,300 kJ/kg, about one-third that of No. 2 fuel oil (Strehler 1980). In a report to Agriculture Canada (Peill 1980a) it was shown that for agricultural conditions and crop rotations at Lyndhurst Farms it was possible to remove yearly an average of 1.25 tonnes of straw per hectare without disturbing the organic balance of the land. This straw could be procured, taking into account all costs, for a 1979 price of $23 per tonne, at a time when No. 2 oil was priced at nearly $200 per tonne. Thus, providing it could be burned efficiently, straw-fuel in this agricultural milieu provided energy at about one-third the cost of furnace oil. The latter report also described the handling and storage of the straw in large cylindrical bales of 300 to 400 kg, and its combustion in a burner which was capable of being loaded with an entire bale at a time and which provided an energy output of five million kJ per hour (described later in more detail). This energy output was used to dry grain and corn in the summer and fall harvest seasons, and to heat a variety of farm buildings in winter. The report also discussed the economics of this operation, such as capital costs and payback times.

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[1] NRCC No. 25176

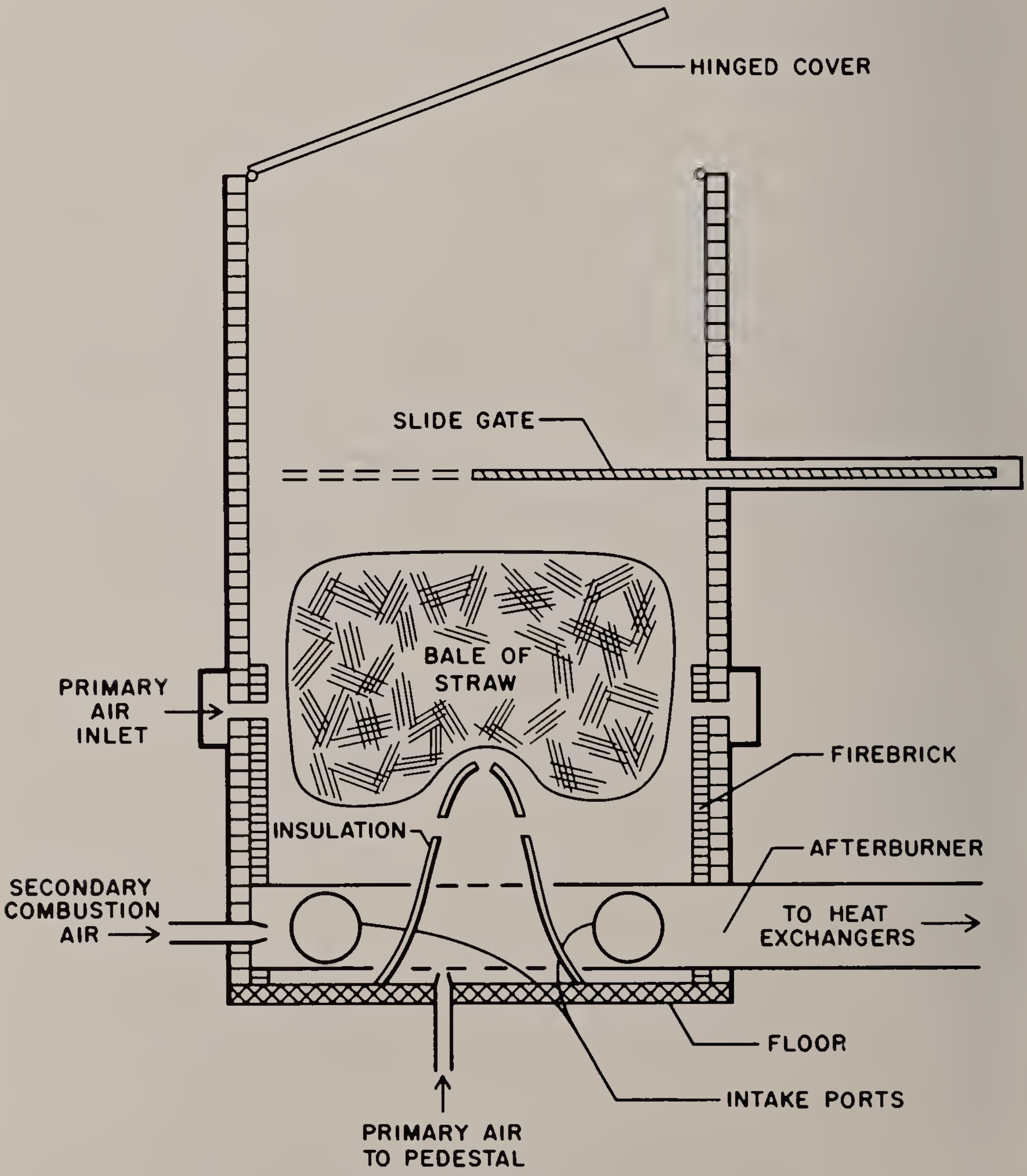

Fig. 1 Schematic drawing of strawburner.

Field Experience with Strawburner

Description of the Strawburner of 1979 design

This strawburner was a vertical steel cylinder, about 2.3 m in outside diameter and 4.5 m in height, lined with insulating fireclay firebrick and having a floor of castable refractory. It burned cylindrical bales of straw 2 m in diameter and 340 kg in weight which were introduced through the lidded top. It had two sections (Fig. 1): the bottom section was the burner proper, and the top section could be locked-off by a sliding gate for introducing a new bale of straw while the burner was in operation.

In the burner section this bale sat on an insulated cone-shaped metal pedestal which was about 1 m high and was cemented into the cast refractory floor of the burner. A tunnel-shaped opening was built into the bottom of the cone to accommodate the horizontally oriented exhaust pipe/secondary burner. Primary combustion air was introduced under pressure to the interior of the cone *via* a pipe set into the floor. The air escaped into the primary combustion chamber through several holes in the walls and tip of the cone, and thus was directed at and into the bale of straw. The cone was fabricated by welding from heavy gauge 0.6 cm stainless steel of the 310 type, and was reinforced by having substantial ribs of the same material welded to its exterior. This reinforcing was necessary because of the stresses imposed when fresh bales were dropped onto the already hot pedestal by retraction of the slide gate. The flow of the combustion air itself helped to cool the underneath of the cone. Primary combustion air also was directed onto the outside of the bale through eight perimeter openings in the wall of the burner.

The exhaust pipe/secondary burner was a heavy gauge stainless steel pipe 35 cm in diameter supported horizontally a few inches above the floor. Four short side-pipes were welded at openings near the ends of the pipe on either side of the superimposed pedestal. These allowed the gases of the primary stage of combustion to be carried into the pipe in a downdraught fashion.

Secondary combustion air was blown axially at one end of the afterburner and the combined primary and secondary combustion gases were emitted from the strawburner at the other end of the afterburner. The hot exhaust gases were used to dry grain and heat water. This was done either directly, or by an appropriate combination of air-air and air-water heat exchangers. The arrangement and sizing of auxillary equipment such as fans, blowers, dampers, and heat exchangers, as well as data on air flows, are given in a report to the National Research Council by ADI Ltd. (Cocci 1980).

Deterioration of Materials in the Original Burner

Problems incurred with the type 310 stainless steel pedestal-afterburner assembly ranged from warping to outright melting. Temperatures achieved under some conditions in the combustion chamber exceeded 1300°C (see below) with the result that slag (molten ash) dripped out of the bale, coated the sidewalls, cone and afterburner, and collected as a dense mass on the floor of the chamber. There was an obvious attack of this slag on the sidewall refractories, and suspected attack on the stainless steel components.

Temperature measuring devices had not been installed in the original burner. During the examination by ADI Ltd. (Cocci 1980) an optical pyrometer was sighted through four openings in the steel shell. These were located approximately 0.6, 1.1, 1.6 and 2.2m above the floor of the burner so that a burning bale could be observed through them. Although temperatures varied widely depending upon wetness of the bale and air supply, many observations taken at various times in the burning cycle showed that most temperatures were in the ranges 1025-1175, 1085-1265, 900-1120, and 900-1120°C for the above locations. Because of the meshed nature of the straw, radiation would approximate black-body conditions, giving reasonable accuracy to these readings. An important observation was that under conditions of exceptional combustion sudden excursions could occur: in one documented case the temperature rose to 1425°C at the third port.

As will be described, in a later modification Pt.-Pt.13%Rh. thermocouples were installed at several locations in the afterburner. It was typical to find that temperatures there dropped to 1000°C when a bale became nearly consumed, and then climbed to and steadied at 1250-1300°C after a new bale was introduced. Again, depending upon particular conditions which seemed to be associated with moisture content, steady temperatures of 1350°C could persist for 10-15 min.

Although the high temperature undoubtedly contributed to the deterioration of materials, it offered two advantages. The first is that total combustion ensured that the flue gases were very clean, and after being cooled by dilution could be used directly to dry grain and corn (with no effect on quality with regard to smell, taste and colour) thereby eliminating the inefficiencies of the air-air heat exchanger. The second was that because the ash was slagged, it did not exit as fly ash but instead collected in the bottom as an easily removed cake having fertilizer value.

Nature of Strawburner Slag

In order to assess the potential for chemical attack by the slag on the refractories and steel components, chemical analyses were carried out on material collected at the bottom. During the corn-drying season the burner would be operated for 22 h out of the 24, with a shut down period to allow the several inches of slag to be removed. In general, this material was dense, glassy, and of a black to dark-green colour; it was also noticeably soluble in water as compared to most metallurgical slags. In addition, different coloured bands were visible, and these could be identified with the eighteen or so bales of straw combusted.

In order to ascertain whether there were compositional differences between these layers a microprobe analysis was carried out using a JEOL 35 scanning electron microscope with Kevex 7000 energy dispersive X-ray spectrometer. A 0.5 x 0.5 cm section, 10 cm thick, was cut from a piece of slag and mounted and polished (in 5 pieces, each of about 2 cm length). The analyses were made in scanning rather than spot mode, usually at a magnification of 10,000. Mineral standards were used for calibration and ZAF corrections applied. In fact, this slag was found to have a fairly uniform composition, regardless of its banding. The averages of nineteen positions within the 10 cm thickness are shown in Table I. These data are given in weight percentages (along with the average deviation from the mean) as well as mole percentages of the oxides.

There were several points of special interest in these results. When CaO and P_2O_5 varied they did so in the same way, the mole ratio CaO/P_2O_5 being nearly three. Possibly this indicates that they occur as $Ca_3(PO_4)_2$ in the straw. Chlorine was sought in the slag but never found, in spite of the fact that unburned hay and straw were found to contain chlorine. In a laboratory experiment dry barley straw was burned in an open fire, the black fluffy ash collected and further sintered in air in a platinum dish, and finally melted to a greenish slag using an oxy-propane torch. Its analysis closely resembled that given in Table I, and in addition there were small amounts of embedded crystals of essentially pure KCl. It is possible that the long burnout time associated with the actual strawburner ensured that all the KCl of the straw was either transformed to K_2O or volatilized.

The composition given previously indicates a complex slag. In order to simplify its description we may express the major components in mole fractions and combine them to give $N_{SiO_2} + 2\ N_{P_2O_5} = 0.67$; $N_{CaO} + N_{MgO} + 2\ N_{Fe_2O_3} = 0.18$; $N_{K_2O} = 0.15$. This

Table I Composition of strawburner slag.[a]

Component	Weight Percent		Mole Percent
SiO_2	55.7	(3.7)[b]	62.0
K_2O	22.0	(0.8)	15.6
CaO	8.7	(1.1)	10.4
P_2O_5	7.9	(1.6)	3.7
MgO	3.9	(0.3)	6.5
Fe_2O_3	2.4	(1.1)	1.0
MnO	0.6	(0.1)	0.6
Al_2O_3	0.3	(0.2)	0.2

[a] Average of 19 determinations.

[b] Figures in brackets are average deviations

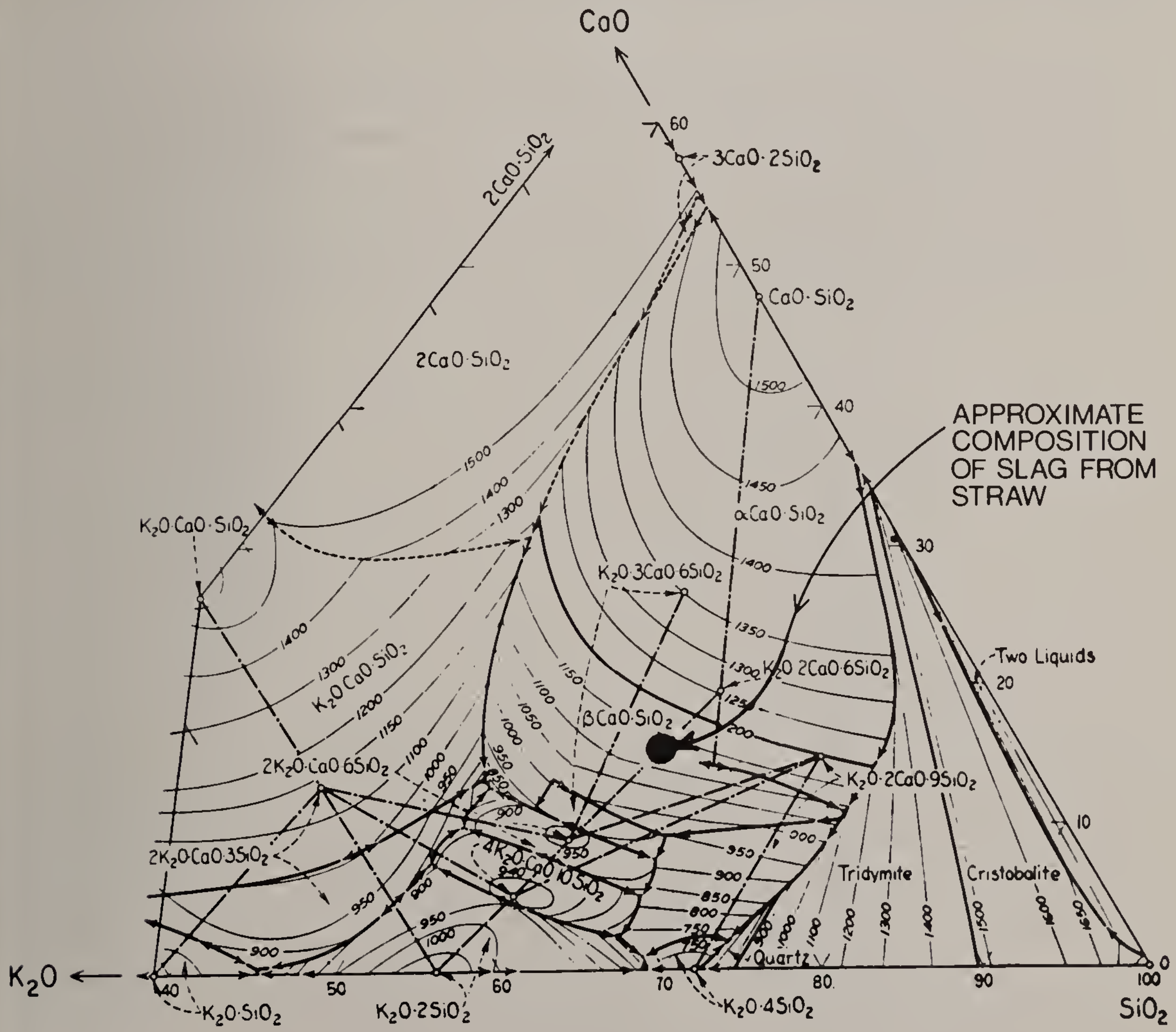

Fig. 2 Approximate location of slag on SiO_2-CaO-K_2O phase diagram, in wt.%.

permits placing the composition on the SiO_2 - CaO - K_2O phase diagram (Morey 1930) suggesting a liquidus at about 1125°C (Fig. 2). While this result must be taken as only approximate because of the somewhat arbitrary assignments of MgO, Fe_2O_3 and P_2O_5, it does indicate the high temperatures that must be generated in the system in order to fuse the ash completely. (The experimental concentrations of P_2O_5 and Fe_2O_3 are given double weight in this calculation because the actual slags are expected to contain species having only one atom of P or Fe.)

Deterioration of Refractories

In the original burner the sidewall refractory was a porous insulating firebrick, rated for 1260°C, of composition SiO_2 - 58%, Al_2O_3 - 37%, with minor quantities of K_2O, TiO_2, FeO, CaO, P_2O_5. It became severely damaged by the slag. This attack was at least partly simple penetration of the liquid slag into the pores, followed by spalling of this surface layer when the slag hardened and contracted after the burning run ended. In addition, chemical attack was suspected, and to examine this a 1.5 cm thickness of slag adhering to the brick was analysed using the microprobe. Concentration profiles are shown in Fig. 3. The distances from 0 to about 0.8 cm represent a reaction zone where the components of the slag and brick have reacted and interdif-

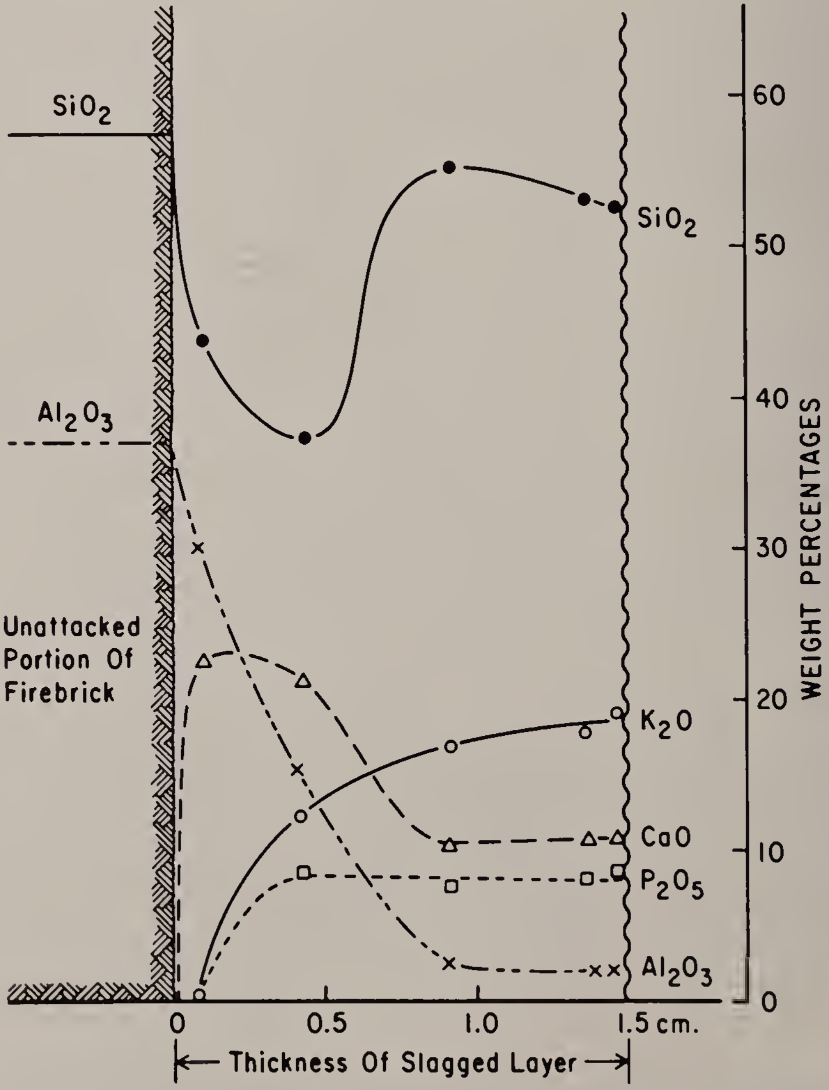

Fig. 3 Reaction zone between slag and refractory firebrick.

fused. The concentration gradients of Al_2O_3, K_2O and P_2O_5 are consistent with this simple picture. The profiles of SiO_2 and CaO are not so simple and suggest a strong tendency toward formation of a compound of CaO and SiO_2. In any case there is evidence of a chemical reaction between slag and brick which would help explain deterioration of the latter.

Later, Lyndhurst Farms replaced this brick with one that was stronger, less porous, and of higher Al_2O_3 content (about 52% SiO_2, 43% Al_2O_3). It was attacked much less severely, and represented a sufficient solution to the problem of attack on the refractory.

Deterioration of the Pedestal - Afterburner

These components were of type 310 stainless steel, an austenitic stainless steel of nominal composition Cr - 25%; Ni - 20; Si - 1.5 max.; Mn - 2.0 max.; Fe - remainder. Its melting point is about 1450°C. A sample cut from a discarded assembly gave, for 22 microprobe positions, an average analysis of Cr - 25.3; Ni - 18.5; Si - 2; Fe - 54.2. The afterburner in use in 1979 had deteriorated quite badly, and sections of the roof of the pipe had collapsed inward, apparently from melting. Some of this collapsed material was analysed and found to be Cr - 15.5; Ni - 21.3; Si-1; Fe - 61.3. It appeared that material which had been subjected to extreme temperatures had been depleted in chromium.

The Metals Handbook (Bardes 1978) reports that type 310 is preferred to other compositions of the general type where intermittent heating and cooling are encountered, since it forms a more coherent scale. Resistance to further oxidation is conferred by this surface layer of Cr_2O_3. It is claimed to be useful for parts such as firebox sheets, furnace linings and boiler baffles, thermocouple wells, and jet engine burner linings. While for temperatures above 925°C type 310 surpasses some of the other stainless steels (e.g. 316) in rupture strength, it has definite temperature limits as far as strength is concerned, as shown by Table II.

Table II Strength of 310 stainless steel.

Temp. (°C)	Tensile Strength (psi.)
Ambient	90,000
425	80,000
650	60,000
870	25,000
1100	7,000

However, because of creep, structures eventually will fail even at temperatures where the tensile strength appears adequate. The available data on rupture time of type 310 does not go beyond 980°C. However, a reasonable extrapolation indicates that a rupture time of 10,000 hours requires an applied stress of no more than 100 psi at about 1150°C, and an applied stress no more than 500 psi at a temperature of 1000°C. It may be supposed that the stress imposed by the dropping of a bale of straw down onto the pedestal-afterburner assembly was responsible for some of the warping observed. In addition, even this grade of stainless steel is limited in its resistance to oxidation at high temperatures, because the protective chromium oxide layer itself fails. It must be assumed that some of the deterioration observed was due to this effect. An important question was whether the slag contributed to accelerating the normal high temperature oxidation. Laboratory experiments, to be discussed later, showed that when the steel was coated by a layer of slag its oxidation rate was actually decreased; however, uncoated parts oxidized unusually rapidly, and this was presumed to be due to the action of a volatile component of the slag.

Strawburner of 1980 Design

It became evident that the favourable economics of the strawburner were being eroded by the high cost of replacing the stainless steel pedestal-afterburner. It was concluded that most of the deterioration problems were related to the high temperatures developed, and that one solution would be to control and lower these temperatures by limiting the supply of primary combustion air, some of which was adventitious infiltration. However the advantage provided by the very clean stack gases, and the requirement of a high energy output during the corndrying season, mitigated against this solution. Therefore, two design changes were introduced, as described in detail in a report to the National Research Council (Peill 1980b).

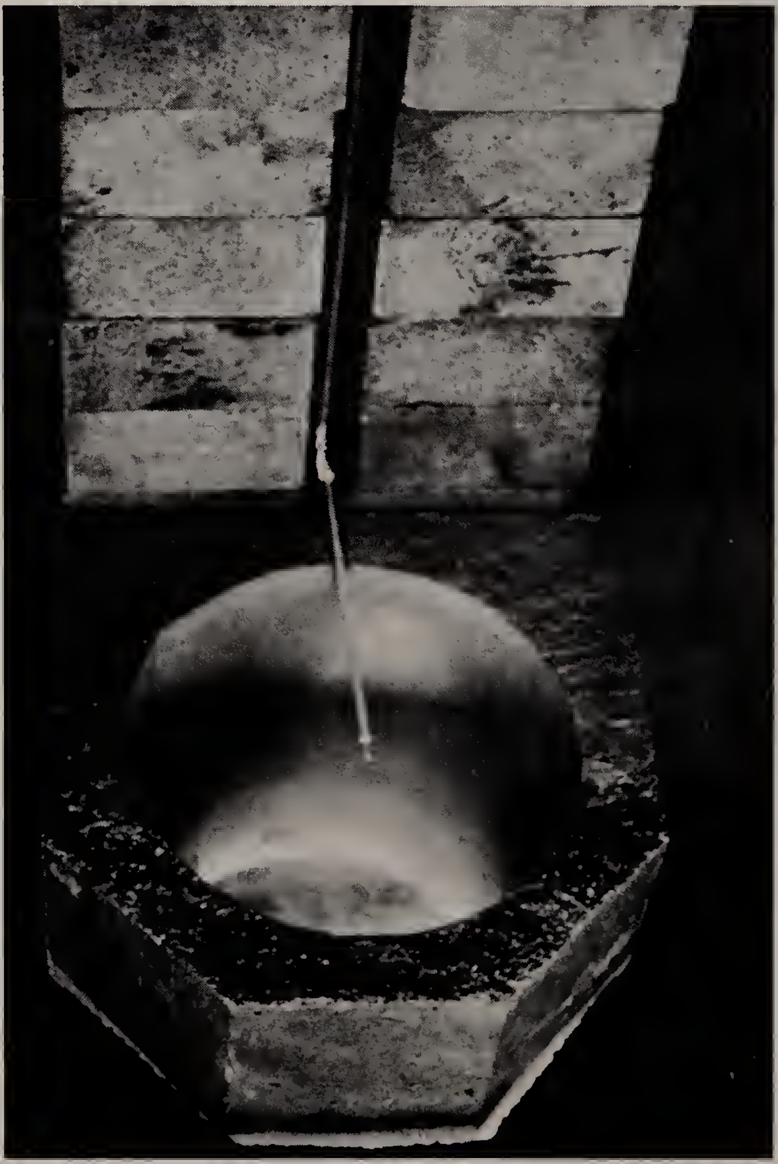

Fig. 4 Castable afterburner segment showing support base of firebrick, and thermocouple installation.

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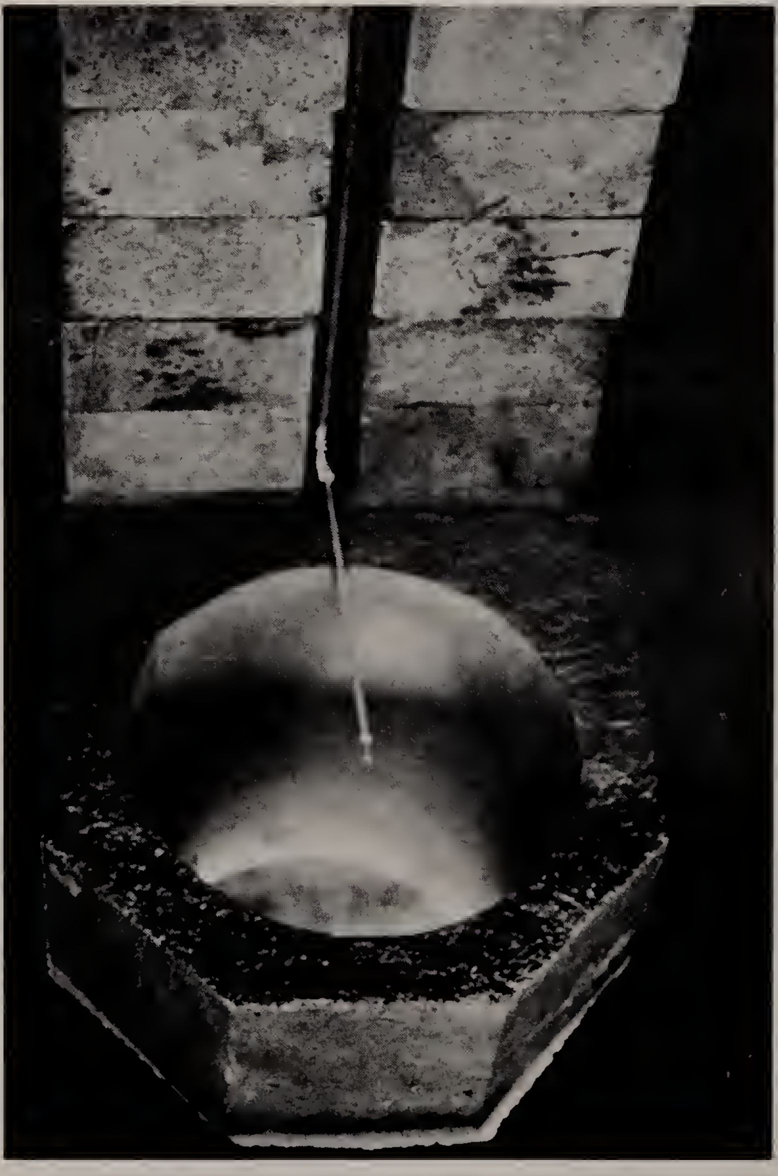

Fig. 4 Castable afterburner segment showing support base of firebrick, and thermocouple installation.

Firstly the cone-shaped pedestal was replaced by a framework fabricated from 5 cm dia. type 316 stainless steel pipe, schedule 80. These pipes also carried the combustion air and it was hoped that the improved heat transfer would keep them sufficiently cool.

The second change was that the afterburner was fabricated from high temperature castable refractory cement. Because of weight, it was cast in four pipe-like sections each 57 cm in length, 40 cm in inside diameter and with wall thickness about 7.5 cm. For experimental purposes four castable cements were used, as supplied by the A. P. Green Firebrick Co.: MC-22, Steelkon GR, Mizzou, and Greencrete ARC. The first three consisted of SiO_2-Al_2O_3-CaO, with increasing temperature ratings of 1290, 1540 and 1650 C respectively because of increasing Al_2O_3 contents. The last was a dense chrome-alumina refractory more abrasion and slag resistant than the others. Figure 4 shows one of these sections being installed on its firebrick base, and the location of one of the three Pt - Pt.13%Rh. thermocouples mentioned earlier.

In general, the cast refractory afterburner was found to be cost-effective. Although temperature cycling caused some cracks to occur they were not serious and did not affect performance significantly. It was concluded that considering economies and ease of fabrication and supply, material of MC-22 or Steelkon grade was the most desirable.

The 316 stainless steel pipe supports for the burning bale were less successful, although the greatest corrosion occurred with mild steel connecting portions used inside the main stainless pipe. It was finally concluded that successful operation of this design required an even better grade of refractory metal of the nickel-chromium type, such as an Inconel. With these modifications the strawburner gave satisfactory performance over several years.

The main fault with this design of burner was that a very large supply of fuel, about 10^6 kJ, was introduced at one time. Close control of combustion therefore rested with controlling the air supply, and this was made difficult by accidental infiltration through the lidded top, doors, etc. Later strawburners designed and fabricated by Biomass Combustion Ltd. (associated with Lyndhurst Farms) were of a type where the feed of straw could be controlled also. This change, together with an internal design that eliminated all metal alloys in the combustion chamber, succeeded in overcoming the problems that have been discussed.

For convenience, the nominal compositions of the alloys mentioned in various places in this paper are given in Table III.

Table III Composition of alloys, wt.%

Alloy*	Cr	Ni	Mo
304 ss	18-20	8-12	-
316 ss	16-18	10-14	2-3
310 ss	24-26	19-22	-
Inconel	14-16	70-75	-

* Iron is the main other constituent in all cases.

Laboratory Experiments

Introduction

Experiments were conducted to assess the effect of various slags on the rate of corrosion of stainless steels and Inconel 600. These experiments will be described in more detail in a separate communication; they consisted of holding 6 cm lengths of 0.64 cm dia. rods of the metals upright in Al_2O_3 crucibles, with the bottom 2 cm immersed in the molten slags. The rods protruded loosely through holes cut in the lids of the crucibles so that for a given temperature and time sections of the rods were exposed to: slag alone; the atmosphere above the slag, including any volatiles; and just air. These test assemblies were then put in a muffle furnace for various lengths of times at various temperatures. The cooled specimens were examined visually for extent of oxidation, and then selected portions were mounted and polished for analysis using the JEOL 35 SEM/microprobe.

Brief Results of Experiments

Experiments using slag taken from the strawburner, with composition close to that of Table I, were carried out. Type 304 and 316 stainless steels were exposed at 1150°C for periods up to 24 hr. These alloys are of the composition Cr - 18, Ni - 10%, but differ in that type 316 contains 2.5% Mo. In general, the bottom part of the specimens covered by the slag showed little or no oxidation. The part outside the crucible can be regarded as normal air-oxidation, and the extent of this oxidation increased with time of exposure. Microprobe analysis showed that the corrosion occurred by surface accumulation of a flaking Cr_2O_3 layer. The apparently sound metal behind this layer exhibited a diffusion gradient in chromium several hundred microns thick, with nickel having diffused back to occupy alloy positions vacated by the chromium. For all conditions type 316 with 2.5% Mo. showed somewhat less deterioration.

The most striking observation was that the portion of the metal samples above the part wetted by the slag, but within the confines of the lidded crucible, exhibited greatly enhanced deterioration over that found in air. This suggested that a volatile component of the slag was enhancing oxidation. Therefore, further experiments were carried out to investigate the cause of this enhanced oxidation. A suspected agent was chlorine in some form; as noted before, slags made in the laboratory from straw contained embedded crystals of KCl, while slag collected from the strawburner did not. For these experiments, synthetic slags were prepared both free of and containing chloride ion. These slags were of composition in weight percent: SiO_2 -39, K_2O - 52, CaO - 8, FeO - 1, with the chloride content obtained by the addition of 1% KCl. Three alloys were tested: types 304 and 316 stainless, and Inconel 600. The temperature used was 1050°C, with exposure times of up to 48 hr.

One important observation was that under these conditions the Inconel 600 showed little or no sign of deterioration. For the other two alloys the extent and type of attack caused by the actual strawburner slag was duplicated. The most important observation was that there was little difference in the extent of oxidation between the chloride-free and chloride-containing slags. We conclude tenatively that chloride is not responsible for the enhanced oxidation. Possibly potassium itself is the culprit. These high potassium contents are a distinguishing feature of straw ash; in ash from other biomass such as deciduous and coniferous wood the potassium is largely replaced by calcium.

Summary

Examples are given of the types of deterioration of materials of construction used in the combustion of straw at high temperatures. The slagged ash can damage refractories if they are not sufficiently dense or of the correct chemical composition. High temperatures and mechanical stresses can damage even type 310 stainless steels. In addition, the normal high temperature oxidation of stainless steels is enhanced by some component of the slag yet unknown. Inconel 600 has been shown to be superior both in laboratory experiments and actual use. Burner parts, made of high-alumina castable refractory cement designed for high temperature use, were shown to be useful and cost-effective.

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FATE OF GLYPHOSATE IN A SANDY LOAM SOIL AND ANALYSIS FOR RESIDUES IN FIELD-GROWN CROPS[1]

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Following application in the spring to a sandy loam soil, residues of glyphosate (N-phosphonomethyl glycine) decreased rapidly and degraded into aminomethylphosphonic acid which also was short lived. Analysis for glyphosate and its metabolite as their methyl trifluoroacetate derivatives was by the flame specific phosphorus gas chromatography. Glyphosate and its metabolite in the soil at 1, 10, 19, 29, 52, 86 and 122 days after application was 69.5, 29.6, 22.1, 14.1, 11.7, 4.2 and 0.0% and 2.3, 31.0, 35.2, 24.0, 15.0, 9.4 and 6.1%, respectively, of the 4.25 kg a.i./ha applied. Neither compound was found in field-grown barley, oat, wheat, sweet corn, beans, peas, red beet or carrots. No injury symptoms were observed on any of the crops during the growing season.

La concentration des résidues de glyphosate (N-phosphonomethyl glycine) décroissant rapidement après d'application à un terreau sablonneux au printemps. Il se dégradait en acide aminomethylphosphonique qui desparaissait rapidement. Le glyphosate et son metabolite sous forme de dérivés methyltrifluoroacetate furent analysés par chromatographie en phase gazeuse à flamme specifique au phosphore. Les concentrations dans le sol, des glyphosate et son metabolite 1, 10, 19, 29, 52, 86 et 122 jours après une application de 4.25 kg a.i./ha étaient de 69.5, 29.6, 22.1, 14.1, 11.7, 4.2 et 0.0% et de 2.3, 31.0, 35.2, 24.0, 15.0, 9.4 et 6.1% respectivement. Aucun composé ne fut retrouvé dans l'orge, l'avoine, le blé, le mais, les haricots, les pois, les belles rouges ou les carottes cultivés dans ces champs. Aucune lésion n'est apparue chez les plants pendant la saison de croissance.

Introduction

Glyphosate (N-phosphonomethyl glycine) is the parent acid formulated as monoisopropylamine salt in the water-soluble herbicide Roundup®. Glyphosate is highly effective as a foliar treatment to weeds and will eradicate many hard to control perennial and annual weeds in a wide variety of cropping practices and non-crop usage. This unique herbicide is useful where herbicides with soil persistence, high mammalian toxicity, or hormone-like activity should not be used, or where the weed population contains a broad spectrum of species.

The initial rapid inactivation of glyphosate in soil is by adsorption (Sprankle et al. 1975; Hance 1976) but degradation occurs by microbial action (Sprankle et al. 1975; Rueppel 1977).

Glyphosate has been used successfully for weed control in numerous horticultural and field crops in Atlantic Canada for several years. However, no studies on residue persistence have been reported. The present study documents the extent of glyphosate residues in several crops and the rate of degradation in soil.

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Materials and Methods

Field Experiment. The experimental sites were at Canard, Nova Scotia, on a sandy loam soil. The soil in site 1 had a pH value of 5.4, organic matter content of 2.7% and a particle-size distribution of 81% sand, 8% silt, and 11% clay. Glyphosate at the rate of 2.75 kg a.i./ha in 300 l water was applied to the whole area in October to control mature weeds that are killed by this treatment. In the following spring the area was rototilled to a depth of 15 cm and divided into 16 plots of 4.5 x 10.5 m with 1.2-m strips separating them and arranged in 4 blocks. About 5 weeks later, when the weed regrowth was about 10 cm high, three plots from each block were sprayed with glyphosate at the rate of 2 kg a.i./ha in 300 l water with a hand sprayer then each plot was randomly seeded with barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.) and wheat (*Triticum aestivum* L.) individually arranged in rows. Site 2 was a fallow area of pH value of 4.8, organic carbon content of 2.9%, and a particle-size distribution of 70% sand, 11% silt, and 19% clay and was divided into four plots of 5 x 7 m with 1-m strips separating them. In late May, three of the four plots were sprayed with glyphosate at a rate of 4.25 kg a.i./ha in 300 l water with a hand sprayer. Ten days later, the plots were rototilled to a depth of 15 cm and each was seeded with oat, sweet corn (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), peas (*Pisum sativa* L.), carrots (*Daucus carota* L. cv. Nantes). and red beets (*Beta vulgaris* L. cv Detroit dark red) individually arranged randomly in rows. The check plot was weeded by hand. At the appropriate harvest time, samples (about 300 g each) of corn kernels, barley, wheat and oat grains, bean and pea pods, and carrots and beet roots were taken at random from each row. Carrots and beet roots were washed with a brush and warm water to remove soil particles adhering to them, then wiped. Soil samples in site 2 to a depth of 15 cm were taken at random with a soil auger at intervals given in Table I. Samples were stored in plastic bags at -20°C until analysed.

The basic procedures described by Kramer (1976) and the Pesticide Analytical Manual (PAM) (1977) for the extraction and clean up of glyphosate and aminomethylphosphonic acid metabolite residues in soil and crop samples were employed. Analysis of the two compounds as their methyl trifluoroacetate derivatives was by flame photometric gas chromatography (Kramer 1976 and PAM 1977). Identity confirmation was made by concentrating appropriate aliquots of original extracts and employing thin-layer chromatography (Ragab 1978). The analytical technique was

Table I Dissipation and degradation of glyphosate in the upper 15 cm depth of a sandy loam soil.[1]

Days after application	Glyphosate (remaining)[3]		Aminomethylphosphonic acid[2] (produced)[3]	
	ppm[4]	%[5]	ppm[4]	%[5]
1	1.48	69.5	0.05	2.3
10	0.63	29.6	0.66	31.0
19	0.47	22.1	0.75	35.2
29	0.30	14.1	0.51	24.0
52	0.25	11.7	0.32	15.0
86	0.09	4.2	0.20	9.4
122	0.00	0.0	0.13	6.1

[1] Applied in the spring at 4.25 kg a.i./ha
[2] Glyphosate major metabolite
[3] Dry weight basis
[4] Assuming the weight of soil in the upper 15 cm depth of a hectare = 2x10^{6} kg
[5] Of the originally applied 4.25 kg a.i. glyphosate/ha (2.13 ppm).

Table II Residues of glyphosate and its aminomethylphosphonic acid metabolite from crops pre-emergent field treated with Roundup® herbicide.

Crop[1]	Glyphosate[2]				Aminomethylphosphonic acid[2]			
	Fortified			Field-treated	Fortified			Field-treated
	Amount added (μg)	Amount found (μg)	Recovery (%)	(ppm)	Amount added (μg)	Amount found (μg)	Recovery (%)	(ppm)
Site 1								
Barley	3.0	2.40	80.0	< 0.05	3.0	2.05	68.3	< 0.05
Oat	3.0	2.43	81.0	< 0.05	3.0	2.10	70.0	< 0.05
Wheat	3.0	2.38	79.3	< 0.05	3.0	2.02	67.3	< 0.05
Site 2								
Oat	3.0	2.41	80.3	< 0.05	3.0	2.01	67.0	< 0.05
Sweet corn	3.0	2.33	77.7	< 0.05	3.0	2.06	68.7	< 0.05
Beans	1.5	1.25	83.3	< 0.05	1.5	0.96	64.0	< 0.05
Peas	1.5	1.20	80.0	< 0.05	1.5	1.06	70.7	< 0.05
Carrots	3.0	1.91	63.7	< 0.05	3.0	1.95	65.0	< 0.05
Red beets	3.0	2.02	67.3	< 0.05	3.0	2.22	74.0	< 0.05

[1] Weight of crops 30 g except beans and peas 15 g.

[2] Recovery % and ppm were on actual (wet) basis. Results were average of 4 determinations (fortified) and 6 determinations (field-treated) on each crop. No glyphosate or its metabolite were found in crop checks. Detection limit of the method 0.05 ppm and < 0.05 denotes 0.00 or no residue.

Site 1: 2.75 kg a.i. and 2 kg a.i. glyphosate/ha in October and following April, respectively.

Site 2: 4.25 kg a.i. glyphosate/ha in May.

verified using check soil and crop samples fortified at the extraction step with 0.1 ppm each of analytical standards of glyphosate and aminomethylphosphonic acid.

Results and Discussion

Table 1 shows that there was rapid disappearance of glyphosate in soil and no residues were left after 122 days of application. The same table shows also that glyphosate degraded to aminomethylphosphonic acid which, in turn, degraded rapidly. These results agree with those of other investigators (Sprankle et al. 1975 and Rueppel et al. 1977).

Table II indicates that there were no measurable concentrations of either glyphosate or its soil metabolite aminomethylphosphonic acid in any of the eight crops grown in the soil treated with glyphosate. The lowest concentration at which compounds could be reliably measured is 0.05 ppm. No injury symptoms such as wilting and yellowing of the plants as a result of glyphosate treatment were observed during the growing season.

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FALL AND WINTER FOOD HABITS OF THE EASTERN COYOTE CANIS LATRANS IN SOUTHEASTERN NEW BRUNSWICK

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Food habits of coyotes in southeastern New Brunswick were investigated during the fall and winter trapping seasons from 1979 to 1982. Based on analyses of 128 specimens, snowshoe hare, white-tailed deer and rodents accounted for 37.5, 27.9 and 27.3% of stomach contents respectively. These data indicate that the coyote shares a common food base with the red fox and the bobcat in the study area.

Les habitudes alimentaires des coyotes du sud-est du Nouveau Brunswick furent étudiées pendant les saison de piégeage d'automne et d' hiver de 1979 à 1982. Des analyses portant sur 128 spécimens ont montré que le lièvre, le chereuil et les songeurs représentaient respectivement 37.5, 27.9 et 27.3% des contenus stomacaux. Ces données indiquent que le coyote partage, avec le renard roux et le lynx une base alimentaire commune dans la région étudiée.

Introduction

Since the late nineteenth century, coyotes (*Canis latrans*) have extended their range throughout the eastern United States and the greater part of eastern Canada (Hilton 1978). They first appeared in New Brunswick in 1966 and have since spread rapidly through the Maritimes.

Previous studies by Knowlton (1964) and Clark (1972) have shown that the coyote's food choices tend to reflect the relative availability of suitable prey. All of these studies were conducted in the western United States, and they were mainly concerned with predators on livestock or big game. In contrast there is little ecological information on coyotes in the mainly forested habitats of eastern Canada, and as a result, there is disagreement among professional biologists and sportsmen as to the role of the coyote within this region. One possibility is that the coyote could compete for prey with other valuable furbearers including the red fox, *Vulpes vulpes rubricosa*, and the bobcat, *Lynx rufus rufus*. A knowledge of the relationship between coyotes and their prey is necessary if we are to predict the impacts the coyote might exert on these predators.

The objective of this study was to examine the food habits of the coyote during the fall and winter seasons within selected counties of southeastern New Brunswick, in order to gather information on its food base.

The study area was located in southeastern New Brunswick and included the counties of Kings, Albert, Westmorland, Kent, Northumberland and Queens. According to Loucks (1968), 70% of the area consists of forested stands dominated by white spruce, *Picea glauca*, tamarack, *Larix laricina* and aspen. The remainder consists of smaller tracts of white pine, *Pinus strobus*, jack pine, *Pinus banksiana*, red maple, *Acer rubrum*, and hemlock, *Tsuga canadensis*. The 30% of non-forested land is mainly farmland, marsh, open water and residential lands.

Methods and Materials

Stomachs were removed from 128 recently shot animals, wrapped in cheesecloth and stored in a 10% formalin solution. Animals were collected from 1979 to 1982.

Stomach contents were analysed following the procedures described by Martin (1949). Hair keys developed by Adorjan and Kolinosh (1969), along with reference collections of skeletons, were used for identification of prey items. Questionable identification of mammal remains or feathers were classified under miscellaneous items.

The data were analysed on the basis of frequency of occurrence and percentage of total weight.

Results

Remains of identifiable food items were found in all of the 128 stomachs examined. Snowshoe hare was the predominant food item, occurring in 51.4% of the stomachs and comprising 37.5% of the total weight of identifiable food items. White-tailed deer remains were found in 31.4% of the stomachs and comprised 27.9% of the total weight. Rodents, while found in 61% of the stomachs, comprised only 14% of the total weight. Livestock (including sheep and cattle) appeared in only 4% of the stomachs and composed less than 1% of the total weight. Ruffed grouse appeared in 8.7% of the stomachs, with an average weight of 2.3%.

Together, snowshoe hare, white-tailed deer, *Microtus* and *Clethrionomys* were the major food items consumed, and they comprised 77.2% of the total stomach content during the fall and winter seasons.

The plant material that appeared in 20.7% and accounted for less than 8.7% of the total weight of all stomach analysis was not identified, as few investigators have considered wild fruit and plants to be important in the coyote's diet (Knowlton 1964)

Discussion

Snowshoe hares were also the most utilized prey in studies conducted by Korschgen (1957), comprising 19 to 61% of the animals diet.

Hawthorne (1972) found rodents to be a staple food item, especially *Microtus*. Clark (1972) has also indicated that when populations are high, *Microtus* could be an important element of the coyote diet.

A survey of the literature indicates that the red fox is also an opportunistic feeder with some marked seasonal variations. Coman (1973) states that there is little doubt that the red fox is primarily a carnivore which preys on snowshoe hare and small mammals. Studies by Besadny (1966) and Johnston (1970) indicate that snowshoe hare and small rodents make up over 56% of the fall and winter diet of the red fox.

Previous studies by Richens and Hugie (1974) and Hilton (1978) have shown that the diet of the coyote is diversified as it seems to consume most available food items. Remains of white-tailed deer were found to be included in all the food studies within the northeastern United States (Hilton 1978). However, Hamilton (1974) concluded that most of these remains were carrion resulting from hunter-killed and winter-killed deer.

A study by Jones and Smith (1979) indicated that bobcats are not strictly opportunistic predators. They seem to maintain their diet even when prey populations fluctuate.

Studies by Stevens (1967) and Pollock (1951) have indicated that the bobcat relies on snowshoe hare, white-tailed deer and small rodents for the greater part of his diet.

A survey of the fur exporting permits for New Brunswick from 1973 to 1979 indicated that a yearly average of 4,322 red foxes and 941 bobcats were trapped. Overall they ranked fourth and fifth amongst the furbearing mammals of New Brunswick.

Table I Percentage occurrence and weight of food items in coyote stomachs from southeastern New Brunswick, 1980-1982

Food Items	Fall and winter samples[1] % occ.	% wt.
Deer		
Odocoileous virginianus	31.4	25.1
Rodents		
Microtus pennsylvanicus (Meadow vole)	43.5	13.0
Clethryionomys gapperi (Red-backed vole)	23.7	8.8
Castor canadensis (Beaver)	7.5	3.4
Ondatra zibethica (Muskrat)	3.5	0.6
Erethizon dorsatus (Porcupine)	15.5	2.8
Hare		
Lepus americanus (Snowshoe hare)	51.5	34.5
Livestock		
Ovis sp. (Sheep)	1.4	0.3
Bos sp. (Cattle)	2.6	0.2
Birds		
Bonasa umbellus (Ruffed grouse)	8.7	2.3
Canachites canadensis (Spruce grouse)	3.5	0.8
Gallus sp. (Poultry)	6.4	1.8
Procyon lotor (Racoon)	6.3	1.4
Miscellaneous (Meat)	9.0	5.0
Plant material	20.7	

[1] Sample size = 128, in total.

The results obtained from this study, along with a review of the results published by Ozoga and Harger (1966), indicate that the bobcat and the red fox share a common food base with the eastern coyote. At the present time, we have few indications of the interspecies relationships which could occur as the coyote increases its population and the major food base enters a downward cycle.

Owing to the relative importance of the red fox and the bobcat as fur bearing animals in New Brunswick, it would seem appropriate that a long term food habit study of the three species would be helpful in fostering a better understanding of the ecological interactions between these major predators.

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IONIC AND MASS BALANCES IN A DILUTE ACIDIFIED BROWN WATER LAKE

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Soldier Lake (1.98 km^2) is an undeveloped, oligotrophic, brown water lake near the Halifax International Airport in central Nova Scotia, which has been acidified from leaching of pyritized metalliferous slates since the 1960s as a result of airport construction and development. Ionic and mass balances demonstrate the effects of strong mineral acids (principally H_2SO_4) and heavy metals from a small segment of the lake's catchment area.

Although based on only two weeks of detailed hydrologic and chemical sampling during the summer of 1983, the study demonstrates significant implications for loading and yield of major ions and heavy metals from widely different substrates within a single catchment.

Water chemistry and hydrology of sub-watershed components from 5-18 July, 1983 show substantial retention (30-80%) of potassium, hydrogen, aluminum, iron, and organic carbon in the lake, while sodium, magnesium, manganese, zinc, chloride and sulfate show little, if any, accumulation within the lake. Calcium shows moderate (19%) retention.

Accelerated weathering of bedrock and tills in the airport segment are reflected in elevated levels of calcium and magnesium in water samples from this portion of the catchment.

Reduction of acid loadings from the airport segment of the watershed (1.7% of the catchment area) could reduce acidic loadings of the lake by 50% and raise Soldier Lake pH by about 0.4 pH units, into the range of 4.8 to 5.0.

Soldier Lake (1.98 km^2) est un lac non développé, oligotrophe dont les eaux sont brunes. Il est situé près de l'aéroport international d'Halifax, au centre de la Nouvelle-Ecosse. Depuis les années 60, le lessivage des schistes métallifères pyriteux causé par la construction et le développement de l'aéroport a provoqué l'acidification de ce lac. Les équilibres ionique et des masses démontrent les effets des acides forts (principalement H_2SO_4) et des métaux lourds prouvenant d'une petite partie du basin versant du lac Soldier.

Même si elle n'est basée que sur deux semaines d'échantillonnage hydrologique et chimique détaillé ayant eu lien pendant l'été 1983, cette étude démontre les implications importantes pour la charge et la production des ions principaux et des métaux lourds prouvenant de substrates largement différents à l'interieur d'un seul Basin.

La chimie de l'eau et l'hydrologie de segments du basin hydrologique, du 5 au 18 juillet 1983, montre une rétention substantielle (30-80 %) du potassium, de l'hydrogène de l'aluminum, du fer et du carbone organique dans le lac, alors que le sodium, le magnesium, le manganèse, le zinc, les chlorures et le sulfates montre une très faible accumulation dans le lac. La rétention du calcium est modérée (19 %).

L'atteration accélérié de la roche de fond et des argiles dans le secteur de l'aéroport est reflétée par les niveaux élévés de calcium et de magnesium dan les échantillons déau provenant de cette partie du basin versant.

Une réduction de la charge en acide provenant du secteur de l'aéroport du basin versant (1.7 % de la surface de captation des eaux) pourrait réduire la charge en acide du lac de 50 % et augmenter le pH dénviron 0.4 unité de pH, dan la zone des pH 4.8 - 5.0.

Introduction and Site Description

Soldier Lake is one of the headwater lakes of the Shubenacadie River system in central Nova Scotia (44° 47′ N, 63° 34′ W) 5 km SW of the Halifax International Airport, a portion of which lies within the lake watershed (Fig. 1). The catchment (36.2 km²) is

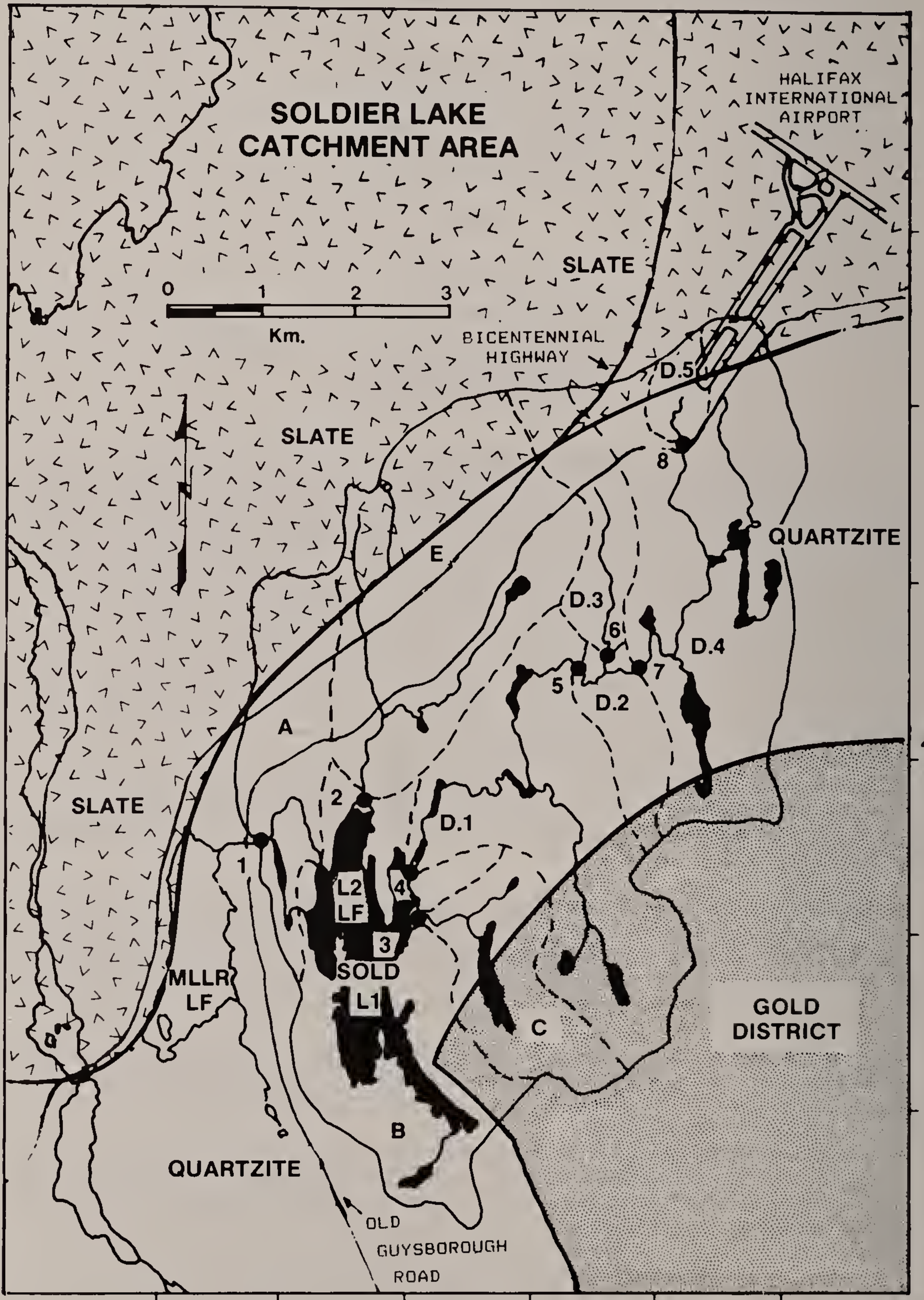

Fig. 1. Location and geology of the Soldier Lake catchment area. Sub-watersheds are identified by letter (A-E), stream sampling stations by number (1-8), and lake water samples by L1, L2, or LF (water samples by Nova Scotia Department of Lands and Forests). MLLR = Miller Lake, SOLD = Soldier Lake. Downstream Shubenacadie lakes shown but not identified.

underlain principally by quartzites of the Meguma formation, with outcroppings of the Halifax slate member in the northern (airport) portion and gold-bearing quartzites in the southern portion of the watershed. Soils are typically thin, composed principally of quartzitic till low in clay and clay minerals. In the northern portion of the catchment near the airport, slates are frequently overlain by up to 2m of a compact, silty clay till.

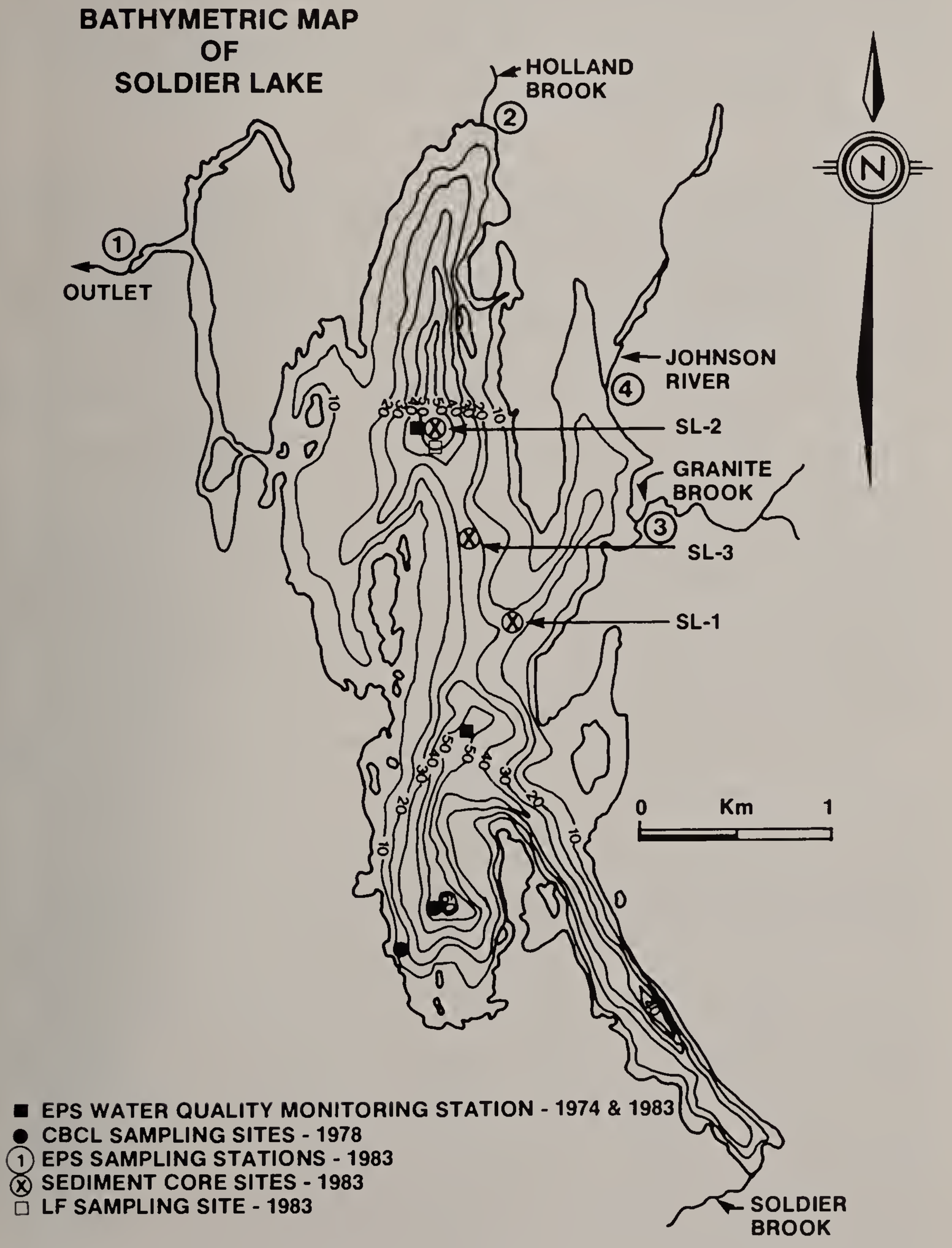
BATHYMETRIC MAP OF SOLDIER LAKE
HOLLAND BROOK
②
①
OUTLET
JOHNSON RIVER
④
SL-2
GRANITE BROOK
③
SL-3
SL-1
N
0 Km 1
10
20
30
40
50
■ EPS WATER QUALITY MONITORING STATION - 1974 & 1983
● CBCL SAMPLING SITES - 1978
① EPS SAMPLING STATIONS - 1983
⊗ SEDIMENT CORE SITES - 1983
□ LF SAMPLING SITE - 1983
SOLDIER BROOK

Fig. 2. Bathymetric map of Soldier Lake showing water and core sampling sites. Numbered open circles are EPS water sampling stations (this study).

The lake (Fig. 2) has a maximum depth of 19.5m and a volume -of 11.3×10^6 m^3. It is polymictic due to rapid flushing time and prevailing winds which parallel the long axis of the lake. Thermoclines mature between 6 and 8 m water depth. Mean annual precipitation (1961-1980) of 1400 mm gives a water retention time of approximately 4 months. Physical characteristics of the lake and sub-watersheds are summarized in Table I.

Table I Soldier Lake Catchment - Physical Data

LOCATION (Outlet) - 44° 49′ 40″ N, 63° 35′ 10″ W NTS - (Uniacke) 11D/13 Edition 4 MCE, Ser. A, 791 UTM - 20T-ME-538 637			
AREA:			
Catchment A_c			3617 ha.
Sub-watershed A + B		613 ha	
Granite Brook C		263 ha	
Johnson River D		1766 ha	
Holland Brook E		777 ha	
Total Watershed		A_w - 3419 ha	
Lake	A_1		198 ha
Islands	A_i	12 ha	
Water	A_o	186 ha	
Watershed: Lake A_w / A_l		17.5	
VOLUME:			
Lake	V_1		11.3×10^6 m^3
Epilimnetic volume	V_e		9.4×10^6 m^3
SHORELINE LENGTH	S_1		14.5×10^3 m
Shoreline Development	S_d		2.9
MAXIMUM DEPTH Z_{max}			19.5 m
Mean Depth $\bar{Z} = V_1/A_1$			6.1 m
Secchi Disc (18 July, 1983)			4.6 m
FLUSHING RATE (1983)			3.1 yr^{-1}

Land clearance and excavation in the Halifax slate associated with construction of the Bicentennial Highway (Rte. 102) and Halifax International Airport in the 1960s are implicated in extensive fish kills and closure of a federal fish hatchery (Thompson 1978). Fish kills in the Johnson River portion of the Soldier Lake catchment have been associated with airport runway extension (Dept. of Lands and Forests, pers. comm.).

Pollen and diatom stratigraphy of short cores (to be published elsewhere) imply a progressive acidification of the Soldier Lake system since initial disturbance by logging operations in the early part of the 19th century. Incomplete historical records indicate that the area has never supported intensive agricultural activity.

At present, the principal disturbances in the watershed include: portions of the Halifax International Airport, a 4 km segment of a major highway (Rte. 102), about 8 km of gravelled roads, and a few small homesteads and cleared areas. Potential future sources of contamination include a new high-technology industrial Park (Aerotech) in the Holland Brook and Johnson River watersheds (D and E, Figure 1).

The pollen stratigraphic record implies removal of white pine (*Pinus strobus*) during the first half of the 19th century, and subsequent high-grading for spruce, hemlock, and perhaps yellow birch. A gradual change to a more open heath woodland is implied by increasing percentages of balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), and Ericaceae pollen.

Although no detailed biological investigations were conducted in the watershed, the consequences of water chemistry of leachate from exposed pyrites resemble those for nearby Springfield and Drain lakes described by Kerekes, *et al.* (1984a).

The area immediately adjacent to the lake has been a Provincial Wildlife Park since the early part of the century. The absence of roads to the lake shore has limited access and intensive recreational use of the lake waters.

Methods

As part of a water quality sampling program by the Environmental Protection Service of Environment Canada, 35 water samples were collected from various portions of the Soldier Lake catchment from 31 May to 23 August, 1983 (approximately biweekly), Samples were analyzed at the water quality laboratories of Environment Canada in Dartmouth, N.S. Major ions, heavy metals, pH, conductivity, colour, and total organic carbon (TOC) were determined by standard procedures and sulphate by the methylthymol blue (MTB) procedure (APHA 1976). Alkalinities were determined by the Gran method following recommended procedures (Anon. 1979).

Precipitation recorded at the Atmospheric Environment Service "A" station at the Halifax International Airport (<5 km to the north) for the sampling period (May-Sept. 1983) was compared with records from the AES "A" station at Shearwater Airport ca. 20 km to the south. No significant differences were found between the two stations.

Runoff data for the sampling period were obtained from the automatic gauging station on the East River at St. Margarets Bay (01EH003), maintained by the Water Survey Branch of Environment Canada. These data are shown in Fig. 3. During the test period of 5-18 July 1983, 38.2 mm of rain fell on the system, amounting to 382 m^3 ha^{-1} on the catchment. Runoff from the East River watershed (the headwaters of which adjoin the Soldier and Miller Lake catchments to the west) amounted to 33.1 m^3 ha^{-1}. These data were used to calculate input/output hydrology and mass balances for the sub-watersheds of the Soldier Lake catchment.

It can be seen from Fig. 3 that runoff for the period 5-18 July, 1983 (shown in black) was quite uniform, and for samples collected on both 5 and 18 July, water chemistry results are also quite uniform. The coefficient of variation (CV) for paired samples during this period was <5%. Variability of multiple samples (n=10) from the airport station between 31 May 1985 and 23 August 1985 ranged from 2.6% for chloride to 29% for sodium. All CV values were less than 20% at the lake outlet for the entire summer sampling period.

Water samples and temperatures at 0,6, and 12 m from two stations in Soldier Lake and a central station in Miller Lake (Fig. 2) indicate only weak thermal stratification and uniform water chemistry throughout the lakes on 18 July 1983. The CV for all lake samples was <6%. Additional water samples taken at sub-watershed outlets (Fig. 1) on 18 July 1983 form the basis for determining the mass balances described in this paper. Ionic balances were calculated for all samples (Table II) using multiple ion sums after Kerekes *et al.* (1982, 1984a, 1984b), and clearly demonstrate the effects of metals, especially aluminum, in acidic waters and the importance of dissolved organic carbon (DOC) in ionic balances.

Additional measured and calculated parameters, sodium: chloride ratio, calcium: magnesium ratio, theoretical pH and conductivity, calcite saturation index (CSI), as well as marine and excess sulfate are discussed elsewhere in this paper.

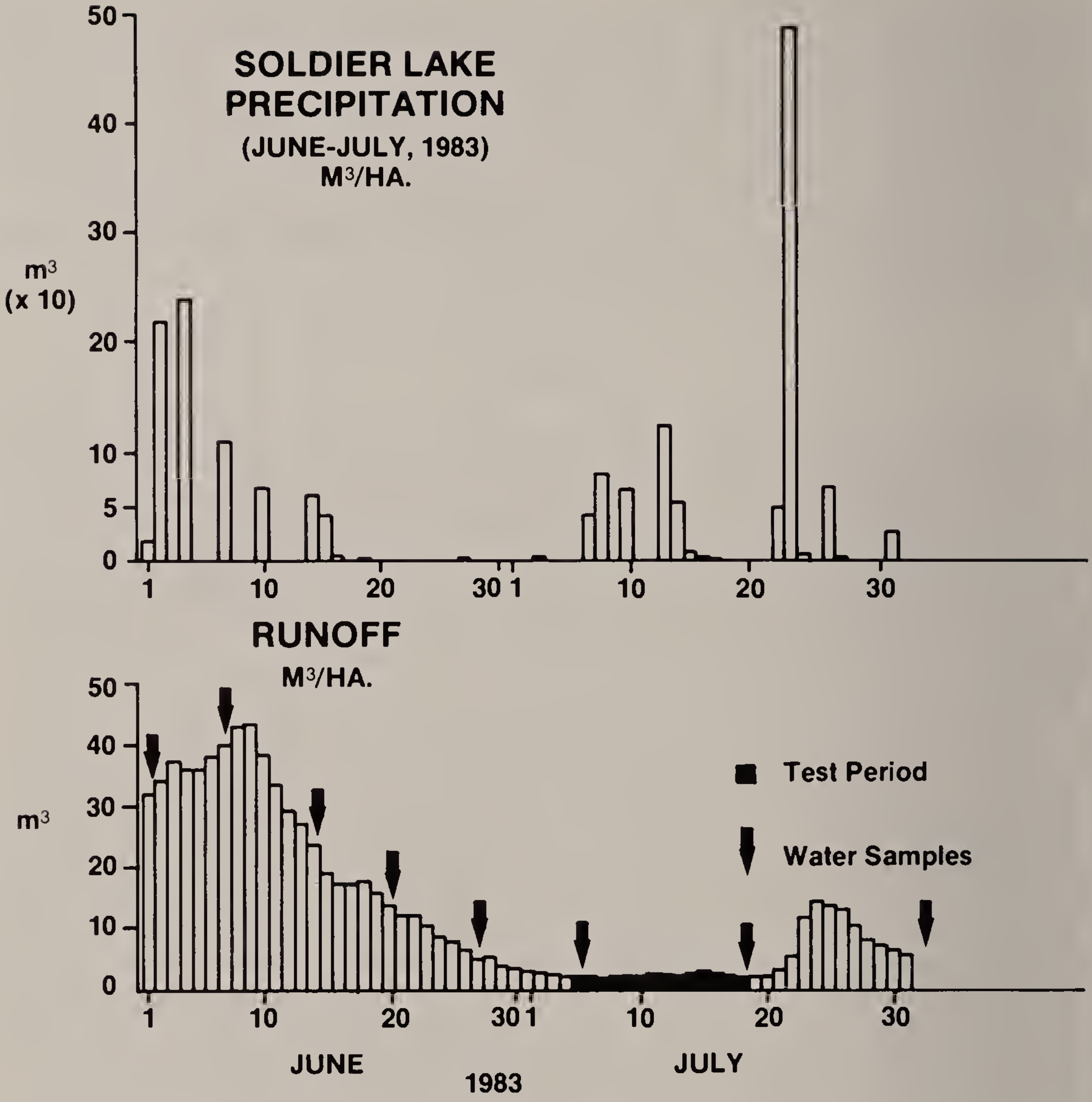

Fig. 3. Precipitation and runoff from the Soldier Lake catchment, summer, 1983. Water chemistry sampling dates shown by dark arrows. Ionic and mass balance study period shown by black runoff values.

Results and Discussion

Raw water chemistry data were converted to microequivalents and are shown in Table II. It can be seen that not only is there an excessive amount of H^+ in the airport samples, but it is probable that accelerated weathering associated with clay tills and bedrock has produced the elevated values of calcium and magnesium observed in these samples.

Ionic balances for Soldier Lake and Miller Lake samples based on major ions (e.g., Cation 1/Anion 1, Table II) are quite acceptable (0.9 - 1.0). The airport samples, however, imply a striking deficiency of cations, or an excess of anions (or both). The following discussion explores the effects of H^+, DOC, and heavy metals on ion balances.

H^+, DOC, Heavy Metals and Ionic Balances

Because of the obvious imbalances apparent for major ions in the airport samples

Table II Soldier Lake System Water Chemistry - Mean values in μeq/L except where specified

Sample Site		Airport Sta.	Johnson River	Granite Brook	Holland Brook	Soldier Lake	Soldier Outlet	Miller Lake
Number of samples		10	1	1	1	9	10	3
Sodium		135	209	83	383	213	220	345
Potassium		53.8	23.1	7.7	17.9	10.8	11.3	6.8
Calcium	(Cation 1)	1475	87.5	25.0	228	80.0	96.5	88.5
Magnesium		1402	68.9	19.7	70.5	49.2	55.7	51.6
H+		1023	66.1	19.5	0.7	25.1	24.0	6.5
Aluminum		1824	63.3	10.0	2.8	25.2	28.9	ND
Iron		687	113	10.2	23.6	6.4	9.7	ND
Manganese	(Cation 2)*	683	25.1	1.1	1.1	14.2	13.7	ND
Zinc		11.1	.9	.5	.5	.5	ND	ND
Other Metals**		16.3	.6	.2	.2	.1	ND	ND
Cations 1		4089	454.6	154.9	700.1	378.1	407.5	498.4
Cations 1 + 2		7310	657.5	176.9	728.3	424.5	459.8	498.4
Chloride		107.2	278.9	112.7	439.4	233.8	234.9	358
Sulfate***		8090	275.9	58.8	121.9	172.3	172.6	158
Nitrate	(Anion 1)	—	ND	ND	1.0	2.0	.5	.5
Phosphate		—	1.0	2.0	1.0	1.4	1.9	ND
Bicarbonate		—	0	0	164	0	0	—
Organic anion	(Anion 2)	13.9	84.5	28.7	15.6	17.3	24.3	8.6
Anions 1		8197	555.8	173.5	727.3	409.5	409.9	516.5
Anions 1 + 2		8211	640.3	202.2	742.9	426.8	434.2	525.0
Cation 1/Anion 1		.499	.818	.893	.963	.923	.994	.965
Cation 1 + 2/Anion 1 + 2		.890	1.027	.875	.980	.995	1.059	.949
Non-marine SO4 (Cl)		8076	332	76	92	165	179	130
Non-marine SO4 (Mg)		7341	335	79	98	164	174	139
Marine SO4 (Cl)		11	28	12	46	28	24	37
Marine SO4 (Mg)		745	35	9	39	26	29	28
Conductivity (μS/cm)		997	90	25	95	56.2	61	71.6
Theor. Cond. (μS/cm)		1067	100	33	86	63.2	64	72.3
Alkalinity (Gran)		—	-76	-20	(164)	-17	-14	—
Calcite Sat. Index		-4.04	-3.65	-4.07	-1.05	-3.35	-3.27	-2.36
Na:Cl (Seawater = .86)		1.348	.763	.732	.869	.913	.958	.964
Ca:Mg (Seawater = .20)		1.097	1.366	1.518	3.103	1.657	1.773	2.269
Colour (T.C.U.)		10.5	225	55	15	11.5	22	5
DOC (calc. mg/L)		2.83	16.8	5.7	3.1	2.89	3.59	2.5
TOC (meas. mg/L)		—	23	10	6	4.41	5.5	—
pH (meas.)		2.99	4.18	4.71	6.18	4.60	4.62	5.19
pH (theor.)		2.31	4.31	4.35	4.82	4.34	4.73	5.73

* Mean valence of + 3 assumed
** Arsenic + Copper + Cobalt
*** MTB-SO4 - A-
— No Data
ND Not Detected

shown in Table II, the contribution of polyvalent metal ions was investigated. It should be noted that MTB sulfate results tend to overestimate sulfate in organic waters due to colour interference (Underwood *et al.* 1982, Kerekes *et al.* 1984b). Sulfate results for Soldier Lake for June, 1983 by other workers using a colour corrected method are lower than the present results by 1.18 mg L^{-1} (25 μeq L^{-1}). This difference reflects the inclusion of organic anions in the MTB sulfate determination as noted by Kerekes *et al.* (1984b). For Soldier Outlet samples organic anions are estimated as 24.3 μeq L^{-1}, and are equal to the observed difference in 1983 lake sulfate values. Therefore, sulfate values in Tables II and III have been corrected by the amount of the estimated organic anion. As shown in Table II, the sum of major cations for the airport station has a mean value of 4.0 meq L^{-1}, with total anions of 8.2, giving a cation: anion ratio of 0.50. Because several of the metal ions analyzed are polyvalent, a mean valence of 2, 2.5, and 3 was tested. As shown in Table II, the sum of metal cations (valence +3) is 3.2 meq L^{-1} for the airport station, yielding a total cation contribution of 7.3 meq L^{-1}, which gives a more acceptable cation: anion balance of 0.89.

The lake outlet samples, on the other hand, give a total major cation value of 0.41 meq L^{-1}, yielding a cation: anion balance of 0.99. Metal ions amount to only 0.05 meq L^{-1} which changes the cation: anion ratio to 1.06.

Although TOC values are shown in Table II, and are consistent with our derived DOC values, we have chosen to estimate organic anion [A^-] from calculated DOC as outlined below.

Underwood *et al.* (1983) have observed a relationship between colour and dissolved organic carbon (DOC) as follows:

$$\mathrm{DOC} = \frac{\text{Colour (Pt/Co)} + 32.59}{15.29}$$

Using formulae developed by Oliver *et al.* (1984) relating organic anions to pH and DOC, a value for organic anion can be estimated. Table II shows that DOC values for the airport station of 2.83 mg L^{-1} gives 13.9 μeq L^{-1} as organic anion. Similarly, for the Soldier Lake outlet samples, a DOC value of 3.59 mg L^{-1} provides an estimate of organic anion of 24.3 μeq L^{-1}. Organic anions have very little influence on the airport station ionic balances, amounting to <.2% (Cations 1+2/Anion 1).

In the more dilute Soldier Lake outlet samples, however, DOC amounts to nearly 6% of the anion sum. The cation: anion value of major ions alone (i.e., cations 1/Anions 1) is 0.99, a very acceptable ion balance. Inclusion of the organic anion (-metals) depresses the ratio to 0.94. Addition of the metal cations brings the ion balance to 1.06. It can be seen (Table II) that in the outlet waters, the organic anions account for nearly 50% of the metal ion equivalents (24.3:52.3).

Measured vs Theoretical pH and Conductivity, Marine vs Excess Sulfate

Table II also demonstrates that theoretical pH = (-Log [(Σ anions - (Σ cations - H^+]) and theoretical conductivity (Σ eq. cond. of each ion (25° C) x conc. (meq L^{-1})) show an acceptable level of agreement in most cases. Differences in theoretical and measured pH average <5% of total cations in all samples except those from Granite Lake Brook (14%) and the airport (53%).

Marine and excess (non-marine) sulfate were determined from magnesium: sulfate and chloride: sulfate ratios in seawater as described in Underwood *et al.* (in press) and Ogden (1980, 1982). Overestimation of marine sulfate for the airport station by magnesium: sulfate ratio reflects the other terrestrial sources of magnesium, presumably from weathering of tills and bedrock. Elevated concentrations of magnesium and calcium are characteristic of the very acidic drainage leaving the airport at a number of locations (unpublished data, EPS). With the exception of the airport station, excess sulfate data, corrected by magnesium: sulfate ratio in sea water, the mean value of marine sulfate contribution (25.7 ± 9 μeq L^{-1}) reflects the >25 km distance of the Soldier Lake catchment from the Atlantic coast (Ogden 1982).

The Granite Brook sample (Sta. 3, sub-watershed C, Fig. 1) is considered to represent "background" water chemistry because of remoteness and lack of roads or development within the watershed. Non-marine, or excess sulfate from this watershed is 76-79 μeq L^{-1} (Table II), or about 7X greater than marine sulfate and is presumably produced by natural weathering, proximity to the Halifax International Airport and urban emissions from Halifax-Dartmouth, as well as distant emissions. Underwood *et al.* (in press) review the water chemistry of 234 rural Nova Scotian lakes and found the average ratio of non-marine: marine SO_4 to be about 3.

Extraordinarily high excess sulfate values from the airport station reflect oxidation of metalliferous pyrite in Halifax slate exposed by airport development which substantially influences downstream and lake water marine and excess sulfate ratios.

Calcite Saturation Index

Conroy *et al.* (1974) present a formula relating pH, calcium and alkalinity which yields a logarithmic value implying sensitivity to acidification. CSI values were determined from the equation;

$$\mathrm{CSI} = \log\left(\frac{[\mathrm{Ca}] \times [\mathrm{HCO_3}]}{[\mathrm{H}]}\right) + \log\left(\frac{K_2}{K_s}\right)$$

where K_2 is the acid dissociation constant of bicarbonate, K_s is the solubility product of calcium carbonate, pH = $-\log [H^+]$ is assumed, and $[HCO_3] = [Alk] + [H]$, which permits calculation of CSI values corresponding to negative alkalinities and assumes that bicarbonate is the dominant base (Wiltshire and Machell, 1981). Alkalinity values for Miller Lake were obtained from unreported outlet data and values for the airport station were estimated from pH.

Values <-3.0 imply a loss of alkalinity and probable failure of fish survival or reproduction. Values >-2.0 imply a reserve of alkalinity and buffering capacity in the soil-water system with decreasing sensitivity to acidification and reduced threat to fish stocks (Malmer 1976).

On this scale, it can be seen in Table II that Holland Brook (CSI = -1.05) is the only station in the entire system that may be considered suitable, or safe, for fish stocks. Parenthetically, it is interesting to note that this is the only station where trout (*Salvelinus fontinalis*) have been observed to spawn successfully in recent years (Dept. Lands and Forests, pers. comm.).

The airport samples are uniformly less than -4.0, and a review of the water chemistry at that station (Table II) implies an extremely hostile environment. The effects of airport drainage persist throughout the lake as the mean Soldier Lake outlet CSI values of -3.27 (n=10) imply substantial risk, especially to salmonids.

Interestingly, the epilimnetic CSI value of -2.36 for Miller Lake may indicate photosynthetic bicarbonate alkalinity returning to Miller Lake, an inference supported by the occurrence of positive Gran alkalinities only during the summer months (unpubl. EPS data) which is also consistent with observations by Schindler (in press) on sources of alkalinity in acid-stressed lakes.

Mass Balance of Major Ions

Table III and IV summarize the hydrology and materials balance for the Soldier Lake catchment for the period 5-18 July 1983. Table III contains the raw data for each of the sub-watersheds sampled in this study.

Individual ions are shown as concentrations (mg L^{-1}), loadings (kg to system) and yield (g ha^{-1}) for the period 5-18 July 1983. The portions of the watershed bordering the lake without defined inflows (Fig. 1, A & B) amount to ca. 17% of the catchment.

Table III Soldier Lake Hydrology and Materials Budget 5-18 July, 1983

Subwatershed (see Fig. 1)		Runway (D.5)	Johnson River (D)	Granite Brook (C)	Holland Brook (E)	D + C + E	A + B (est.)
Sample Station		Sta. 8	Sta. 4	Sta. 3	Sta. 2	—	—
Area (% of total)		61 ha (1.7%)	1766 ha (48.8%)	263 ha (7.3%)	777 ha (21.5%)	2806 ha (77.6%)	613 ha (16.9%)
Water Output (1000 m^3)		2.02	58.5	8.7	25.7	92.9	20.3
SODIUM							
conc.	mg/l	4.4	4.8	1.9	8.6	—	—
load	Kg	8.9	281	17	226	524	40
yield	g/ha	146	159	64.6	291	186.7	65.3
POTASSIUM							
conc.	mg/l	2.5	.9	.3	.7	—	—
load	Kg	5.1	52.7	3	18	73.7	7.1
yield	g/ha	83.6	29.8	11.4	23.2	26.2	11.6
CALCIUM							
conc.	mg/l	35	1.8	.5	4.6	—	—
load	Kg	70.7	105.3	4	118.2	227.5	9.5
yield	g/ha	1159	59.6	15.2	152.1	81.1	15.5
MAGNESIUM							
conc.	mg/l	25.3	.8	.24	.9	—	—
load	Kg	51.1	46.8	2	23.1	71.9	4.8
yield	g/ha	838	26.5	7.6	29.7	25.6	7.8
H+							
conc.	mg/l	1.413	.066	.0195	.001	—	—
load	Kg	2.85	3.9	.17	.026	4.1	.4
yield	g/ha	46.7	2.2	.6	.033	1.5	.7
ALUMINUM							
conc.	mg/l	18.1	.57	.09	<.025	—	—
load	Kg	36.6	33	.8	<.6	33.8	1.9
yield	g/ha	600	18.7	3	<.8	12	3.1

IRON							
conc.	mg/l	11.9	2.12	.19	.44	—	—
load	Kg	24	124	1.7	11.3	137	4
yield	g/ha	393	70	6.5	14.5	48.8	6.5
MANGANESE							
conc.	mg/l	—	.46	.02	.02	—	—
load	Kg	—	26.9	.2	.5	27.6	.5
yield	g/ha	—	15	.8	.6	9.8	.8
ZINC							
conc.	mg/l	.31	.02	.01	<.01	—	—
load	Kg	.63	1.2	.1	<.3	1.3	.2
yield	g/ha	10.3	.7	.4	—	—	.3
SULFATE**							
conc.	mg/l	452	13.2	2.8	5.9	—	—
load	Kg	933	722	24.4	152	948	56.8
yield	g/ha	15299	437	92.6	195	338	92.7
CHLORIDE							
conc.	mg/l	4	9.7	4	15.6	—	—
load	Kg	8.1	567	34.8	401	1003	82
yield	g/ha	133	321	132	516	357	134
ORG. CARBON							
conc.	mg/l	2.79	16.9	5.73	3.11	—	—
load	Kg	5.6	983	50	80	1113	116
yield	g/ha	92	557	190	103	397	190

* Based on runoff est. 33.1 m³ ha^{-1} (see text).

** MTB-SO_4 - A

Table IV Summary Hydrology and Materials Balance, Soldier Lake, N.S., 5-18 July, 1983

		SOLDIER IN 3419 ha (94.5%) 188.8*	SOLDIER OUT (Sta. 1) 3617 ha (100%) 119.7	Input - Output Lake load in Kg	% Retention in Lake
SODIUM					
conc.	mg/l		4.6		
load	Kg	564	551	13	2.3
yield	g/ha		152		
POTASSIUM					
conc.	mg/l		.4		
load	Kg	81	47.9	33	40.7
yield	g/ha		13.2		
CALCIUM					
conc.	mg/l		1.6		
load	Kg	237	191.5	46	19.4
yield	g/ha		52.9		
MAGNESIUM					
conc.	mg/l		0.7		
load	Kg	76.7	85.0	8.3	10.8
yield	g/ha		23.5		
H+					
conc.	mg/l		.025		
load	Kg	4.5	3.0	1.5	33.3
yield	g/ha		.8		
ALUMINUM					
conc.	mg/l		.2		
load	Kg	35.7	24	11.7	32.8
yield	g/ha		6.6		
IRON					
conc.	mg/l		.18		
load	Kg	141	21	120	85.1
yield	g/ha		5.8		
MANGANESE					
conc.	mg/l		.26		
load	Kg	28	31	-3	(10.7)
yield	g/ha		8.6		
ZINC					
conc.	mg/l		<.01		
load	Kg	<1.5	<1.2	<.3	—
yield	g/ha		—		
SULFATE**					
conc.	mg/l		8.8		
load	Kg	1005	1053	-48	(4.8)
yield	g/ha		291		
CHLORIDE					
conc.	mg/l		8.1		
load	Kg	1085	970	115	10.6
yield	g/ha		270		
ORG. CARBON					
conc.	mg/l		3.77		
load	Kg	1229	451	778	63.3
yield	g/ha		125		

* NOTE: SOLDIER IN includes watershed Runoff (113.2 DAM^3) plus precipitation on lake (75.6 DAM^3).
Difference (69.1 DAM^3) is attributed to evaporation from the lake surface (3.5 cm) for the sample period.
** MTB - SO_4 - A-

Loading and yield values were calculated from measured Granite Brook samples. We have termed this portion the "residual watershed." These values are discussed for each of the ions in the following section of this paper.

Table IV summarizes the sub-watershed contributions to Soldier Lake (SOLDIER IN). The terrestrial (watershed) portion of the catchment is 3419 ha (94.5%) and system total precipitation input is 188.8 dam^3. SOLDIER OUT summarizes the system outlet hydrology (119.7 dam^3 which includes lake evaporation of 3.5 cm, confirmed by readings from a standard evaporation pan maintained by the Halifax Urban Watershed Program for the period 5-18 July 1983; HUWP, D. Thirimurthi, pers. comm.). Data are shown as mean concentration, loading, and yield, based on outlet water chemistry.

Table IV also reviews the fate of major ions in the Soldier Lake system for the two-week study period, and indicates that the lake is a major sink for potassium, hydrogen, aluminum, iron, and organic carbon (30-80%). Lesser amounts of calcium (19%) are retained within the lake. Sodium (2%), magnesium (11%), and chloride (11%), are retained poorly, if at all. The implication that the lake is a source for manganese (-3 kg) or sulphate (-48 kg) is not acceptable, as both the number of samples and the brief sampling period (two weeks) are insufficient to provide confidence in such small differences (5-11%).

The following considers each of the individual ion concentrations, loads, and yields throughout the system:

Sodium

The yield of sodium from the Granite Brook sub-watershed (C) of approximately 65 g ha^{-1} presumably represents normal or background values from atmospheric input of marine aerosols and rock weathering (considered to be a minor source in Meguma bedrock). Elevated concentrations and yields from the Runway area (Sta. 8, Fig. 1), Johnson Brook (Sta. 4, Fig. 1), and Holland Brook (Sta. 2, Fig. 1) reflect seasonal leaching of road salt applied to the Bicentennial Highway and the Goffs/Guysborough (gravel) road which crosses the northern part of the watershed.

Potassium

An external source for potassium is possibly associated with the inferred calcitic and dolomitic sources in sub-watersheds E and D referred to previously. In any event, the load to Soldier Lake (74 kg) from 78% of the total watershed is sharply diminished in the lake (48 kg at the outlet) implying that the lake is a sink for potassium, a property earlier noted by Hart and Ogden, (1977) for the Fink Cove system.

Calcium

Loading and yield calculations for this element imply about 19% removal of calcium in the lake. If the background concentration of calcium is about 0.5 mg L^{-1} (Granite Brook, sub-watershed C), system loading to the outlet should be about 52 kg. Because the drainage from sub-watersheds D and E is a source of calcium, the total system input is ca. 237 kg. The outlet value, 191.5 kg indicates retention (presumably in lake sediments) of about 19% of the calcium entering the lake during the study period.

Magnesium

Background (Granite Brook) yield values (7.6 g ha^{-1}) imply a normal loading of ca. 28 kg at the lake outlet. The fact that the sum of measured inputs to the lake (77 kg) is similar to the output value (85 kg) implies that little, if any, magnesium is retained in the system.

H+

System loading values (>4.5 kg in, vs. 3.0 kg out) indicate consumption of at least 33% of the H+ entering the system. Interestingly, system yield at the outlet (.8 g ha^{-1}) is only 25% greater than from the undisturbed area represented by Granite Brook (.6 g ha^{-1}).

A mass balance model, based on water chemistry input and output values using data from a "background" watershed source (Granite Brook) implies that restoration of the Runway segment of the Johnson River system to output loading values from the Granite Brook system would reduce the H^+ loading from the Johnson River by at least 50% and of the entire Soldier Lake system by 25%. A reduction in $[H^+]$ of this magnitude could raise Soldier Lake pH values by 0.4 pH units, into the range of pH 4.8 to 5.0.

Sulfate

Despite a prodigious yield of sulfate from the airport runway segment of nearly 15 kg ha^{-1}, the outlet loading is only about triple the inferred background value based on Granite Brook (92.6 g ha^{-1} x 3617 ha = 335 kg). It can be seen that about 72% of the sulfate delivered to Soldier Lake is from sub-watershed D, and that a substantial amount of sulfate is retained in the Johnson Brook segment of the watershed. Total sulfate inputs and output values imply little change in sulfate loading within Soldier Lake during the study period.

Chloride

Since the residual watershed (613 ha) would presumably add no more than about 81 kg (based on Granite Brook yield), the difference in system loading (1085 kg) and Outlet (980 kg) is not considered significant.

Aluminum

With a possible total system loading of about 36 kg of aluminum, an outlet value of 24 kg indicates retention of ca. 33% within the system. It is also clear that the Johnson Brook segment (48% of the catchment area) provides >90% of the aluminum delivered to the lake.

Iron

Total system loading for iron is about 141 kg, based on estimates from the residual watershed using Granite Brook yield (6.5 kg from 613 ha). Since the outlet apparently releases only 21 kg, more than 80% of the iron is presumably precipitated within the lake.

Manganese

The residual watershed contributes about 0.5 kg of manganese to the system for a total input of approximately 28 kg. Outlet values of 31 kg imply no retention of manganese within the Soldier Lake system and lead to the testable hypothesis that changes in iron and manganese ratios in sediments may reflect varying H^+ loadings from disturbance within the watershed.

Zinc, Cobalt, Copper, and Arsenic

Analytic values for these substances are in general below detection limits at the outlet, and in most of the lake input samples. An anomalous value of 0.13 mg L^{-1} of arsenic at the outlet is not accepted because it implies a system loading of 15.6 kg, for which the only apparent source, the runway segment (D.5) is clearly inadequate (0.24 kg).

Conclusions

Water chemistry results in summer 1983 show that the Johnson River subwatershed of Soldier Lake is primarily responsible for acid and heavy metals loading of Soldier Lake. The Johnson River watershed (ca. 50% of the Soldier Lake catchment) contributed approximately 85% of the H^+, 92% of the aluminum, and 88% of the iron entering Soldier Lake during a two-week period in July 1983. Also, 63% of the H^+ loading came from 1.7% of the catchment area (Airport Station).

Of a total of 141 kg of analytically detected iron entering Soldier Lake, only 21 kg were accounted for at the outlet, implying substantial retention within the lake, presumably by coprecipitation with organic anions of which 63% (778 kg) were retained.

This study clearly demonstrates that Johnson River is the principal source of acid and heavy metals to the Soldier Lake system, and that control measures implemented in a small segment of the watershed (Airport Station = 1.7% of catchment area) could substantially reduce acid loadings to the entire system.

These results also imply that future development of the Aerotech Park will require careful management to prevent further deterioration of an already severely stressed aquatic ecosystem.

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SEASONAL VARIATION IN THE NONSTRUCTURAL CARBOHYDRATE COMPOSITION OF RHIZOMES OF FOREST UNDERSTORY SPECIES

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Rhizomes of eight forest understory species were analyzed in spring, summer and autumn for total nonstructural carbohydrate (TNC) content partitioned as sucrose, free reducing sugars (FRS), fructosans and starch. Species studied were: *Maianthemum canadense* Desf., *Pteridium aquilinum* (L.) Kuhn, var *latiusculum* (Desv.) Underw., *Cornus canadensis* L., *Kalmia angustifolia* L., *Vaccinium angustifolium* Ait., *Gaultheria procumbens* L., *Chamaedaphne calyculata* (L.), Moench, Var. *angustifolia* (Ait.) Rehd., and *Rhododendron canadense* (L.) Torr.

TNC concentrations were highest in *M. Canadense* (56%-70% over the seasons) compared to 7% - 30% in the other species. They were highest in autumn for all species except for *P. aquilinum*. The most abundant single component of TNC was starch for all species except *M. canadense*, in which the fructosan concentration was highest The storage polymers formed at least 95% of TNC in all cases and showed distinct seasonal changes. The concentrations of FRS and sucrose were always low (4% and 1.5% of TNC respectively), and showed no direct correlation with seasonality.

Les rhizomes de huit espèces de plantes du sous-bois forestier furent analysés au printemps, en été et en automne dans le but de déterminer leur contenu total en carbohydrates non structuraux (TNC); ces carbohydrates non structuraux se divisaient en sucrose, en sucres réducteurs libres, en fructosans et en amidon. Les espèces suivants furent étudiées : *Maianthemum canadense* Desf., *Pteridium aquilinum* (L.) Kuhn, var. *latisculum* (Desv.) Underw., *Cornus canadensis* L., *Kalmia angustifolia* L., *Vaccinium angustifolium* Ait., *Gaultheria procumbens* L., *Chamaedaphne calyculata* (L.), Moench, Var. *angustifolia* (Ait.) Rehd., and *Rhododendron canadense* (L.) Torr.

Les concentrations en TNC furent les plus élevées chez *M. canadense* (56%-70% sur toutes les saisons) comparativement a 7%-30% chez les autres espèces. Les concentrations les plus fortes furent enregistries en automne chez toutes les espèces excepté *P. aquilinum*. L'amidon représentait la fraction des TNC la plus importante chez toutes les espèces excepté *M. canadense*. La concentration en fructosan était la plus élévee chez cette espèce. Les polymères composant les réserves réprésentaient au moins 95 % des TNC chez toutes les espèces et montraient des variations saisonnières distinctes. Les concentrations eu FRS et en sucrose furent toujours faibles (4 % et 1.5 % respectivement), et n'ont montré aucune corrélation avec les saisons.

Introduction

Rhizomes are important as storage organs for energy reserves (Menke & Trlica 1981, Gallagher 1983). Stored reserves of starch (Townsend et al 1968, Smith 1969, Garrison 1971, Sturges & Trlica 1978) or fructosan (Smith 1969, Meier & Reid 1982) will influence the ability to regenerate following disturbance (Trilica & Cook 1971). Defoliation through disturbances such as fire, cutting and herbicide spray will result in changes in the source-sink relationship in plants because of loss of leaf photosynthesis (Watson & Caspar 1984). Rhizome role and clonal growth have been reviewed by Ashmun et al 1982 but confusion has arisen in the literature with respect to whether vegetative propagation is simply part of the growth and perennation strategy of a single genetic individual (the genet) as suggested by Kays and Harper (1974) or whether asexual reproduction serves a role of greater significance when it results in the production of physiologically independent ramets (Cook 1979). Production of numerous independent ramets can increase the survivorship of a locally adapted genet (Williams 1975; Abrahamson 1980). It was, therefore, important in this research to excavate rhizome material that was independent, so as to eliminate the possibility of genetic similarity.

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There has been considerable interest in recent years in the control of forest understory species using a variety of disturbing influences such as cutting, burning, and treatment with herbicides. A significant part of this interest relates to the ability of plants to regenerate after such treatment and some evidence has been obtained linking carbohydrate reserves with this ability (Kausch et al 1981). However, little effort has been channelled into examining the nature of carbohydrate reserves in the underground parts of wild plants. We therefore wished to examine the quantity and type of carbohydrate storage products present in the rhizomes of some forest understory species. We also wanted to determine how this storage varied seasonally and how the quantity of nonstructural carbohydrates for each species relates to regrowth data obtained previously (Flinn 1980). We feel that answers to these questions will assist in deciding when defoliation treatments should be carried out to effect minimum regrowth of certain species (e.g. *Kalmia angustifolia*) that are competitive in the silvicultural management of the Acadian forest or maximum regrowth of commercially viable species such as *Vaccinium angustifolium.* We therefore chose these species along with six others for this study. All are common and prevalent species (number/m^2) beneath the hardwood and spruce-fir overstories of the Acadian forest (Flinn 1980) and all regenerate from surviving below-ground rhizomes.

Materials and Methods

Field Collection

The eight species studied were: *Gaultheria procumbens, Maianthemum canadense, Vaccinium angustifolium, Cornus canadensis, Pteridium aquilinum, Kalmia angustifolia, Chamaedaphne calyculata* and *Rhododendron canadense.* Taxonomic identification and nomenclature of species were based on Roland and Smith (1969). The field sites were described by Flinn and Pringle (1983). Rhizomes (25-50 cm long) were randomly collected from a range of habitats, i.e. spruce-fir, spruce and hardwood overstory, in the Nova Scotia Acadian forest in spring (June 1), summer (August 1) and Autumn (October 1) as described by Flinn and Pringle (1983). Seasonal collection for each species came from the same habitat, i.e. the summer collection of a particular species was taken from the same location as the spring habitat for that species. An attempt was made to ensure that, although the species came from the same habitat, they were from different populations. This was done by randomly selecting different locations in the same habitats separated by at least 10 m. More material had to be collected for rhizomes of smaller diameter such as *M. canadense* in order to have enough material for the analysis.

All samples were transported to the laboratory within one hour of excavation. They were washed, killed by fast oven drying, and dried completely at 70°C (up to 12 h depending on rhizome diameter). Dried rhizomes were ground in a Wiley Mill (1 mm mesh) for 30 sec and stored at room temperature. There was no significant change in the TNC after 6 months storage.

Variation in the total non-structural carbohydrate (TNC) content between rhizomes of a single species was determined for both *Chamaedaphne calyculata* and *P. aquilinum.* Individual rhizomes (50 cm long) from randomly chosen sites were dried, weighed, washed, ground, and then analyzed separately. Pooled samples were also prepared by grinding together rhizomes from at least 10 different plants for each of the eight species to give a sample of at least 4 g of rhizome tissue for analysis.

Extraction and Chemical Analysis

Pulverized samples were extracted with 80% ethyl alcohol at 70°C for 3 h (Heinze & Murneek 1940) and filtered through Whatman No 1 filter paper. Free reducing sugars in the 80% ethanol-soluble fraction were determined by a modification of the method of Shaeffer and Somogyi (Smith 1969; Ku et al 1978). The amount of sucrose in this fraction was determined by difference in reducing sugars before and after hydrolysis with 0.1 N H_2SO_4 for 15 m in a boiling water bath.

The starch in the 80% ethanol-insoluble material was determined by analysis of reducing sugars after complete hydrolysis of starch with crude alpha-amylase that contained maltase activity ("Takediastase" from *Aspergillus oryzae*, Sigma Chemical Co.). After drying at room temperature, the ethanol-insoluble materials were treated with 0.14% (w/v) alpha-amylase in buffer, pH 4.45, at 37°C for 48 h. The incubation mixture was filtered through Whatman No 1 filter paper. The filtrate was deproteinized by addition of saturated lead acetate, de-leaded with potassion oxalate and assayed for reducing sugars.

Fructosan in the deproteinized filtrate was determined by difference in reducing sugars before and after hydrolysis of the filtrate with 0.1N H_2SO_4 in a boiling water bath for 15 min. Hydrolysis of fructosans was complete (Smith 1969) and thin layer chromatography was used to confirm that fructose was the only sugar released during hydrolysis of the filtrate (Hay et al 1963). Calculations (per cent of total dry weight of sample) for each of the carbohydrate components were based on those described by Smith (1969) for determining TNC.

Statistical Analysis

Calculations of means, standard error of means, one- and two-factor analysis of variance were done using the statistical package SAS on a VAX 11/750 computer.

Table I Rhizome nonstructural carbohydrate components contributing to total carbohydrate reserves.

Nonstructural carbohydrate component		*Chamaedaphne calyculata*	*Pteridium aquilinum*
Mean FRS (%)	spring	0.28 ± 0.04 a	3.60 ± 0.25 a
	summer	0.42 ± 0.04 a	2.31 ± 0.30 b
	autumn	0.41 ± 0.06 a	1.78 ± 0.26 b
Mean sucrose (%)	spring	0.12 ± 0.03 a	0.10 ± 0.04 a
	summer	0.05 ± 0.01 a	0.02 ± 0.01 a
	autumn	0.12 ± 0.05 a	0.14 ± 0.07 a
Mean starch (%)	spring	7.28 ± 0.48 b	23.45 ± 1.45 a
	summer	9.08 ± 0.47 a	21.26 ± 3.53 a
	autumn	8.73 ± 0.36 a	8.46 ± 4.00 b
Mean fructosans (%)	spring	1.92 ± 0.44 a	0.99 ± 0.27 b
	summer	0.64 ± 0.26 b	2.14 ± 0.52 a
	autumn	0.59 ± 0.15 b	0.50 ± 0.32 b
Mean TNC (%)	spring	9.60 ± 0.52 a	28.16 ± 1.38 a
	summer	10.18 ± 0.51 a	25.73 ± 3.74 a
	autumn	9.85 ± 0.34 a	10.89 ± 4.30 b

For each species and variable, seasonal means labelled with different letters are statistically significantly ($p < .05$) distinct from each other, as determined by the Student-Newman-Keuls test, an a *posteriori* multiple range test. (± standard error of the mean for all cases, n = 10).

Results and Discussions

Variability in TNC content between individual rhizomes of *Chamaedaphne calyculata* was within 5% of the mean for all three seasons but *Pteridium aquilinum* showed much greater variability from one season to another (Table I). In spring TNC content in individual rhizomes of *P. aquilinum* was within 5% of the mean, but the range increased to over 10% in summer and to almost 40% in autumn. This high variation among rhizomes in autumn TNC content may be attributed, at least in part, to a depletion of reserves during rhizome elongation. Furthermore, many of the older segments of *P. aquilinum* rhizomes die off in autumn resulting in loss of TNC. *Vaccinium angustifolium* and *Kalmia angustifolia* have also been analyzed for TNC in individual rhizomes (Flinn et al unpublished) and show variability ($<5\%$ of the mean) comparable to that reported here for *Chamaedaphne calyculata*. These trends, similar to those observed by Townsend et al (1968) for *V. angustifolium* indicate that in general, variation in TNC is low among rhizomes of physiologically independent ramets. Thus, we are confident that data obtained using pooled samples of rhizomes from a single species (Fig. 1) reflect the TNC content of individual rhizomes of that species.

The FRS, sucrose, starch, and fructosan fraction differed significantly ($p<.05$) between *Chamaedaphne calyculata* and *P. aquilinum* (Table 1). There were significant differences within each species between mean seasonal levels of FRS, starch, and fructosans, but no significant difference between mean seasonal levels for sucrose in either species. The mean seasonal levels of TNC were significantly different from *P. aquilinum* but not for *Chamaedaphne calyculata* which indicated that the seasonal pattern of accumulation of carbohydrate reserves differed greatly for the two species (Table 1, Fig. 1). *P. aquilinum* showed a much higher concentration of TNC (especially starch) in spring and summer, followed by a dramatic decrease in autumn when the two species showed similar concentrations. The elevated starch levels in *P. aquilinum* during spring and summer were accompanied by relatively high FRS content during the same periods. It has been observed over a five year period that this is a time of rapid rhizome elongation in this species and the associated metabolic activity may require elevated levels of reducing sugars as precursors for anabolic growth pathways. Gallagher et al (1984) found that rhizomes of salt marsh plants showed a similar distinct concentration cycle for nonstructural carbohydrates.

There were clear similarities in TNC content for pooled rhizome samples of the five ericaceous species (Fig. 1), with spring values forming 11-15% (of total dry weight), summer 10-17%, and autumn 15-20%. The TNC was highest in autumn for this family and was most often lowest at the spring sampling. The slight deviation from this pattern for *Chamaedaphne calyculata* and the more pronounced effect in *K. angustifiolia* may be a reflection of phenological differences for these evergreen species.

There was less TNC in *Cornus canadensis* during the spring than in any other species studied. This may be due to depletion of reserves during flowering and fruiting (Ting 1982). Fruiting was in progress in this species during the time of spring sampling.

The quantities of TNC were markedly greater in *Maianthemum canadense* (Fig. 1) due to the high accumulation of fructosans in this species. This observation is consistent with well documented reports that fructosans (fructans) are the major reserve carbohydrates of monocotyledons (Ting 1982, Smith 1969, Meier & Reid 1982). There were small amounts of fructosan in the spring or summer analyses of the 6 dicotyledon species examined (Fig. 1). The role of these fructosans is not clear. Starch content for *M. canadense* was comparable to that of other species.

All species except *P. aquilinum* showed the greatest starch or fructosan content in the autumn. This confirms results from studies on other plant parts in other species

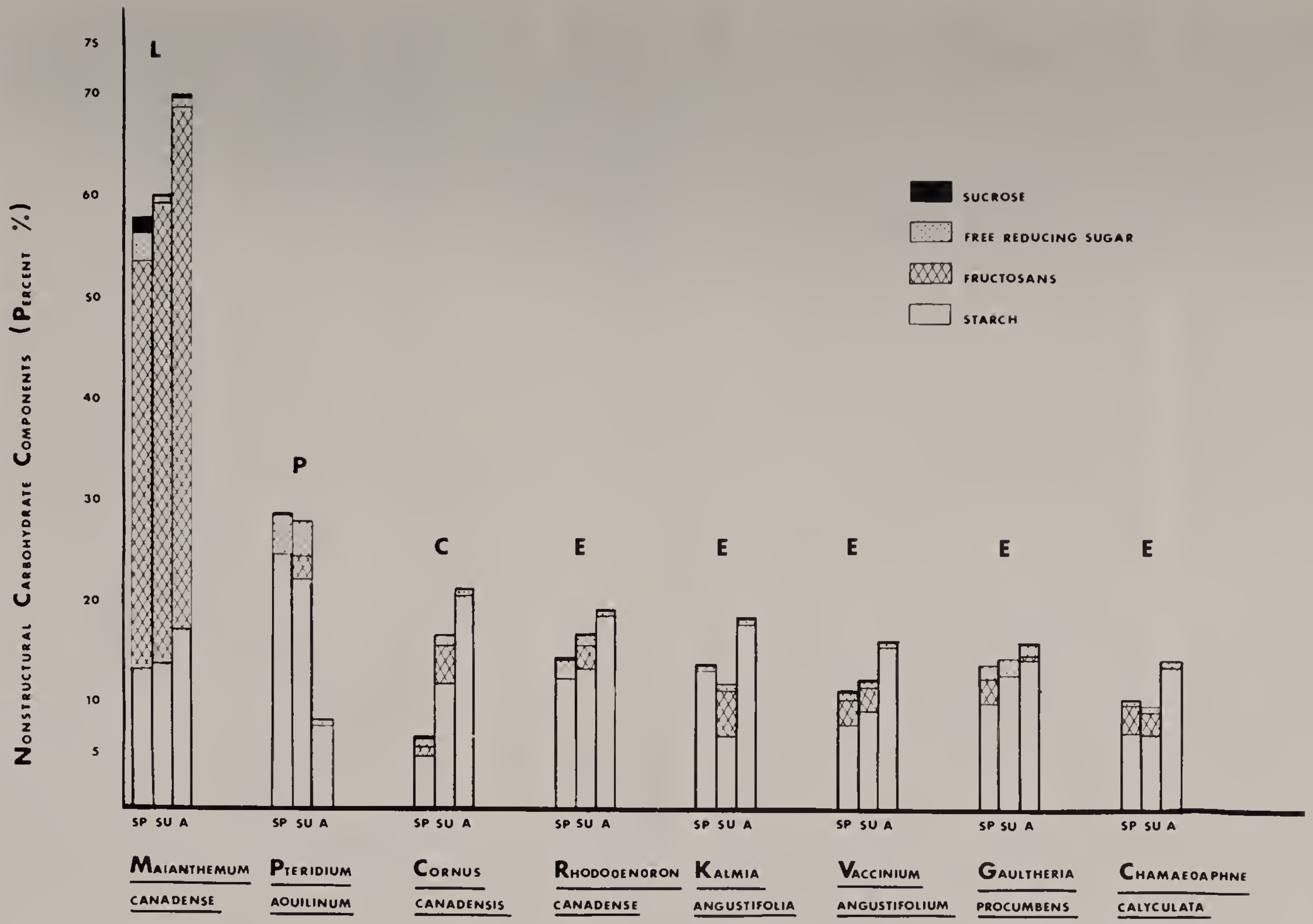

Fig. 1 Per cent of total dry weight of sucrose, free reducing sugar, fructosans and starch making up total nonstructural carbohydrate in pooled rhizome samples of eight forest understory species collected in early June (Sp = spring), August (Su = summer), October (A = autumn), grouped according to families: L = Liliaceae, P = Polypodiaceae, C = Cornaceae and E = Ericaceae.

(Lindahl et al 1949, Mooney & Billings 1960, Edelman & Jefford 1968, Townsend et al 1968, Smith 1969, Chubey & Dorell 1977, Roseff & Bernard 1978, Gallagher 1983, Gallagher et al 1984). The marked seasonal differences in TNC for very different species (Fig 1) such as *M. canadense* and *P. aquilinum* and the similarities observed for more related species (ericaceous family) strongly support the notion that each individual species has a distinct cycle for concentrating reserves in the rhizomes (Gallagher et al 1984, Ashmun et al 1982).

Free reducing sugars formed less than 4% of TNC in all species for all seasons. The data was significantly different ($P<0.05$) between species but not between seasons. This indicates that monosaccharides such as glucose function as precursors for biosynthesis (Preiss 1982).

The results presented here clearly indicate characteristically different patterns of carbohydrate storage in the rhizomes of different understory plants in the Acadian forest. On the other hand, more closely related species show similar patterns of carbohydrate reserve accumulation. A common feature for most species studied was the peak accumulation of nonstructural carbohydrate in the autumn. Since available reserves would be expected to influence the ability of these plants to regenerate following stress (Kausch et al 1981), this helps to explain the earlier observation (Flinn 1980) that such regrowth after fire was greatest if burning was carried out in autumn. Therefore, from this research, the most effective control of forest understory species in silvicultural management might be anticipated if defoliation were carried out in spring when rhizome carbohydrate reserves are low.

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LIGNICOLOUS MARINE FUNGI FROM PRINCE EDWARD ISLAND WITH A DESCRIPTION OF DIDYMOSPHAERIA LIGNOMARIS SP. NOV.[1]

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Twenty marine fungi, 13 ascomycetes and 7 deuteromycetes, were isolated from 5 sites in waters around Prince Edward Island. Fungi were isolated from blocks and panels of birch, spruce and pine wood submerged for 5 months and from intertidal and driftwood. All are first reports for the coast of P.E.I. Most of the fungi are common in the region. *Didymosphaeria lignomaris* Strongman and Miller is described as a new species and *Cirrenalia macrocephala* is reported for the first time from Atlantic Canada.

Les auteurs ont isolés vingt mycètes marines, 13 ascomycètes et 7 deuteromycètes, dans cinq endroits dans les eaux côtières de l'Ile-du-Prince-Edouard. Les mycètes ont été isolés sur des blocs et des morceaux de panneau de bouleau, épinette et pin submergés pendant cinq mois, et aussi sur bois soit de la zone intertidal, soit sur la ligne de plage. Tous ces mycètes sont signalés pour la premier fois le long de la côte de I-P-E; la plupart sont assez common dans la région. *Didymosphaeria lignomaris* est decrite comme une nouvelle éspece, tandis que *Cirrenalia macrocephala* est signalée pour le première fois dans le Canada Atlantique.

Introduction

Three provinces of Atlantic Canada have been investigated for the presence of lignicolous fungi. Meyers and Reynolds (1960) isolated marine fungi from submerged wood at Halifax and Liverpool. N.S.; St. Andrew's, N.B.; and Argentia, Nfld. Hughes (1968) recorded marine fungi on driftwood from two sites on the eastern coast of Nfld. The Bay of Fundy, located between N.B. and N.S., has been extensively studied. Neish (1970) isolated marine fungi from driftwood at 7 sites on the N.S. coast. Boland and Grund (1979) reported fungi on wood and *Spartina* species from the salt marshes of the Minas basin. Miller and Whitney (1981) described fungi from intertidal and drift wood at 8 sites and from submerged panels at 1 site on the N.B. coast of the Bay of Fundy.

One area of the Atlantic provinces that has not been investigated for the presence of marine fungi is in the waters around Prince Edward Island. These waters are part of the Gulf of St. Lawrence and have different hydrographical characteristics than the waters at the places listed above (i.e.) higher average surface temperatures in summer and coverage by ice all winter. Details of the physical and biological features of coast of P.E.I. can be found in Stephenson and Stephenson (1954a,b).

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[1] CBRI Contribution Number *1595*.

This paper reports lignicolous marine fungi found at 5 sites on the coast of P.E.I. and describes a new species of the genus *Didymosphaeria*.

Materials and Methods

Sites

Site 1 (46° 35.5′ N 63° 51.5′ W) is in Malpeque Bay, a sheltered bay opening on the north shore of P.E.I. Sites 2 (46° 33′ N 63° 51.5′ W), and 3 (46° 33′ N 63° 41′ W) are on the north shore of P.E.I. The north shore has a 10-20 m horizontal tidal range, high energy beaches and severe ice scouring. Sites 4 (46° 24.5′ N 64° 0.85′ W) and 5 (46° 24′ N 64° 06′ W) are on the south shore of P.E.I. These areas have a 20-30 m horizontal tidal range, moderate energy beaches and moderate ice scouring. Vertical tidal range at all sites is 1-3 m. Summer surface water temperatures average 19-21°C, with slightly warmer temperatures on the south shore. Surface water temperatures can reach extremes of 25°C at most of the sites. Summer salinities in the area average 27-30 ‰. In the winter ice formed at all sites.

Collection techniques

Three types of wood cut into panels and blocks were submerged from May to October at sites 1, 3 and 4 in 1983 and sites 1, 2 and 4 in 1984. The types of wood used were: birch (*Betula alleghaniensis* Britton), spruce (*Picea glauca* (Moench) Voss) and pine (*Pinus strobus* L.). Panels were 14 cm x 10 cm x 2 cm and blocks were 2.5 cm x 2.5 cm x 2.0 cm. Before submergence the wood was sterilized by steaming for 1 hr at 100°C then for a further hour after 24 hr at room temperature. Panels were strung together with polypropylene rope in a "sandwich" arrangement (Meyers & Reynolds 1958), each string consisting of two sets of three panels of the same type. Blocks (ten of any one type per bag) were placed in fiberglass screen bags (20 cm x 30 cm) and tied 60 cm apart on polypropylene rope. The panels and blocks were transported to each site in sterilized plastic bags. Submersion consisted of placing panels and blocks, two sets of each, at each site so that they were covered by about 0.5 m of water at low tide.

After five months the wood was collected and put into sterilized plastic bags. In addition, intertidal and driftwood were collected from the beach at sites 1, 3 and 5 and placed in sterile plastic bags. All the wood was transported, on ice, to the laboratory in Fredericton, N.B. where it was stored at 5°C, pending isolation and identification of the fungi present.

Isolations and identification

Isolation of fungi from the wood were made onto artificial medium within 5 days of removal of the wood from the water. The medium consisted of glucose (1 g), yeast extract (0.1 g) and agar (18 g) in 1L of seawater 28 ‰ (Johnson & Sparrow 1961) plus penicillin G and streptomycin sulphate (0.5 g/L of each). Either ascospores, conidia or hyphae were streaked on the surface of the medium in Petri dishes. The dishes were incubated at 25°C in the dark until until growth occurred. Pure cultures were obtained by transferring, to cornmeal-artificial seawater (Lyman & Fleming 1940)-agar medium, single-spore isolates in the case of spores, and hyphal-tip isolates in the case of hyphae. These were stored at 5°C on 2% malt extract-seawater agar or seawater agar slants.

For identification and voucher of these fungi permanent slides were made using the technique described by Kohlmeyer and Kohlmeyer (1979). Identification was based on ascocarp, ascus and spore characteristics. The slides were deposited in the Connell Memorial Herbarium (UNB) at the University of New Brunswick, Fredericton, N.B.

Results and Discussion

A total of 20 lignicolous marine fungi were isolated including one new species. All the fungi listed are first reports for the coast of P.E.I. Although the hydrographic characteristics around P.E.I. are different from the waters around the other Atlantic provinces, the fungi are similar. Description of these 20 fungi follows:

Ascomycetes

1. *Ceriosporopsis halima* Linder, in Barghoorn and Linder, Farlowia 1:409, 1944.

Ascospores 23-26 x 9-10 (-13) μm (excluding appendages).

Habitat: submerged panels (spruce (sp), pine (p) and birch (b)), and blocks (sp, p, b) at sites 1, 2 and 4. Intertidal wood at sites 1 and 3. Previously reported in Nova Scotia (Neish 1970) and the Bay of Fundy (Miller & Whitney 1981). Other Canadian reports noted in Booth (1981).

2. *Ceriosporopsis tubulifera* (Kohlm.) Kirk, in Kohlmeyer, Can. J. Bot. 50:1953, 1972.

Ascospores 21-26 x 10-13 μm (excluding appendages).

Habitat: intertidal wood (site 3). Ascocarps were deeply embedded under ascocarps of *Halosphaeriopsis mediosetigera* in well-rotted pieces of intertidal wood. Previously reported in the Bay of Fundy (Miller & Whitney 1981), in Nova Scotia (Neish 1970) and Newfoundland (Hughes 1968) as *Halosphaeria tubulifera*. Other Canadian reports noted in Booth (1981).

3. *Corollospora maritima* Werdermann, Notizbl. Bot. Gart. Berlin 8:248, 1922.

Ascospores (26-) 31-33 x 7.5-8 μm.

Habitat: submerged panels (sp, b) at site 1, (sp) at site 2; blocks (sp, p, b) at site 1, and intertidal wood at site 1. This fungus was found fruiting on sand or mud stuck on wood as well as on the wood itself. Previously reported in the Bay of Fundy (Miller and Whitney 1981) and in Nova Scotia (Neish 1970). The other Canadian report is from British Columbia (Hughes 1969).

4. *Halosphaeria appendiculata* Linder, in Barghoorn and Linder, Farlowia 1:412, 1944.

Ascospores 23.5-26 x 10-13 μm (excluding appendages).

Habitat: submerged panels (b) at sites 1 and 4; blocks (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981), Nova Scotia (Neish 1970) and Nfld. (Hughes 1968). The other Canadian report is from British Columbia (Hughes 1969).

5. *Halosphaeria hamata* (Hohnk.) Kohlm. Can. J. Bot. 50: 1956, 1972.

Ascospores 23.5-28.5 x 8-13 μm.

Habitat: submerged panels and blocks (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and in Nova Scotia (Neish 1970; Boland & Grund 1979). The other Canadian report is from British Columbia (Hughes 1969).

6. *Halosphaeriopsis mediosetigera* (Cribb et Cribb) T.W. Johnson, J. Elisha Mitchell Sci. Soc. 74:44, 1958.

Ascospores 39-44 (-48) x 15-20 μm.

Habitat: intertidal wood at sites 1, 3 and 5; submerged panels (b) at site 4. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Boland & Grund 1979) as *Halosphaeria mediosetigera*. Other Canadian reports noted in Booth (1981).

7. *Leptosphaeria oraemaris* Linder, in Barghoorn and Linder, Farlowia 1:413, 1944.

Ascospores 21-23 x 5-7 μm. One septum at equator of spore.

Habitat: intertidal wood at sites 3 and 5. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Neish 1970).

8. *Lulworthia* sp.

Ascospores (182-) (195-) 220-286 (-364) x 3-5 μm. These ascospores had a conical apical chamber at each end and a large guttule at the midpoint of the spore.

Habitat: submerged panels (sp, b) at sites 1, 2 and 4; blocks (sp) at site 4 and (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981), Nova Scotia (Neish 1970) and Nfld. (Hughes 1968). Other Canadian reports noted in Booth (1981). We agree with Hughes (1968) and Kohlmeyer and Kohlmeyer (1979) that further taxonomic research is needed to separate species.

9. *Nais inornata* Kohlm., Nova Hedwegia 4:409, 1962.

Ascospores 26-31 x 13-15 μm.

Habitat: submerged blocks (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Boland & Grund 1979). Other Canadian reports noted in Booth (1981).

10. *Nereiospora cristata* (Kohlm.) Jones, Johnson and Moss, Botanical Journal of the Linnean Society 87:206, 1983.

Ascospores 33-41 x 12-16 μm (excluding appendages).

Habitat: intertidal wood at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981), Nova Scotia (Neish 1970) and Nfld. (Hughes 1968) as *Corollospora cristata* (Kohlm) Kohlm. The other Canadian report is from British Columbia (Hughes 1969).

11. *Remispora pilleata* Kohlm. Nova Hedwegia 6:319, 1963.

Ascospores (28.6-) 31.2-36.4 x 18.2-20.8 μm (excluding appendages).

Habitat: intertidal wood at sites 1 and 4. Previously reported in Nfld. (Hughes 1968) and the Bay of Fundy (Miller & Whitney 1981) as *Halosphaeria pilleata* (Kohlm) Kohlm. The other Canadian report is from British Columbia (Hughes 1969).

12. *Sphaerulina oraemaris* Linder, in Barghoorn and Linder, Farlowia 1:413, 1944.

Ascospores 28.6-33.8 x 7.8-10.4 μm.

Habitat: submerged panels (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Neish 1970).

13. *Didymosphaeria lignomaris*, Strongman and Miller, sp. nov. Fig. 1, a-f.

ASCOCARPI: (187.5) 220-312.5 μm in diametro, 225-250 μm alti, subglobosi, partim aut totaliter immersi, ostiolati, papillati, nigri. PERIDIUM: 30-70 μm crassum, prosenchymaticum, superficie verruculosa emergentibus crassitunicatis et orbicularibus cellis, nigrum ad superficiem, hyalinum prope venter. PAPILLAE absentes aut curtae, 35 μm altae, 100-120 μm in diametro; ostiolatus canalis 30-45 μm in diametro. PSEUDOPARAPHYSES 1-2 μm in diametro, filiformes, affixae ad ambas fines. ASCI 120-135 μm, octospori, cylindrici, bitunicati, crassitunicati, sine acroapparatibus, crescentes in strato ad fundamentum ascocarpi ventris. ASCOSPORAE 24.7-26 x 10-11.7 μm, uniseriatae, ellipsoedeae, uniseptatae in medio, colligatae ad septum, subtiliter echinulatae, crassitunicatae, phaeoincrassatae circum apices, luctuosae circum septum. HABITAT in ligno. TYPUS: Herb DAOM 193904 (HOLOTYPE). ASCOCARPS (187.5) 220-312.5 μm diameter, 225-250 μm high, subglobose, partly or totally immersed, ostiolate, papillate, black (Fig. a). PERIDIUM 30-70 μm thick, prosenchymatous, surface verruculose by emerging round thick-walled cells, black at the surface, hyaline near the venter (Fig. b,c). PAPILLAE absent or short, 35 μm high, 100-120 μm in diameter, ostiolar canal 30-45 μm in diameter. PSEUDOPARAPHYSES 1-2 μm in diameter, filiform, attached at both ends. ASCI 120-135 μm, eight spored, cylindrical, bitunicate thick walled, without apical apparatuses, developing in a layer at the base of the ascocorp venter (Fig. b, e, f). ASCOSPORES 24.7-26 x 10-11.7 μm, uniseriate,

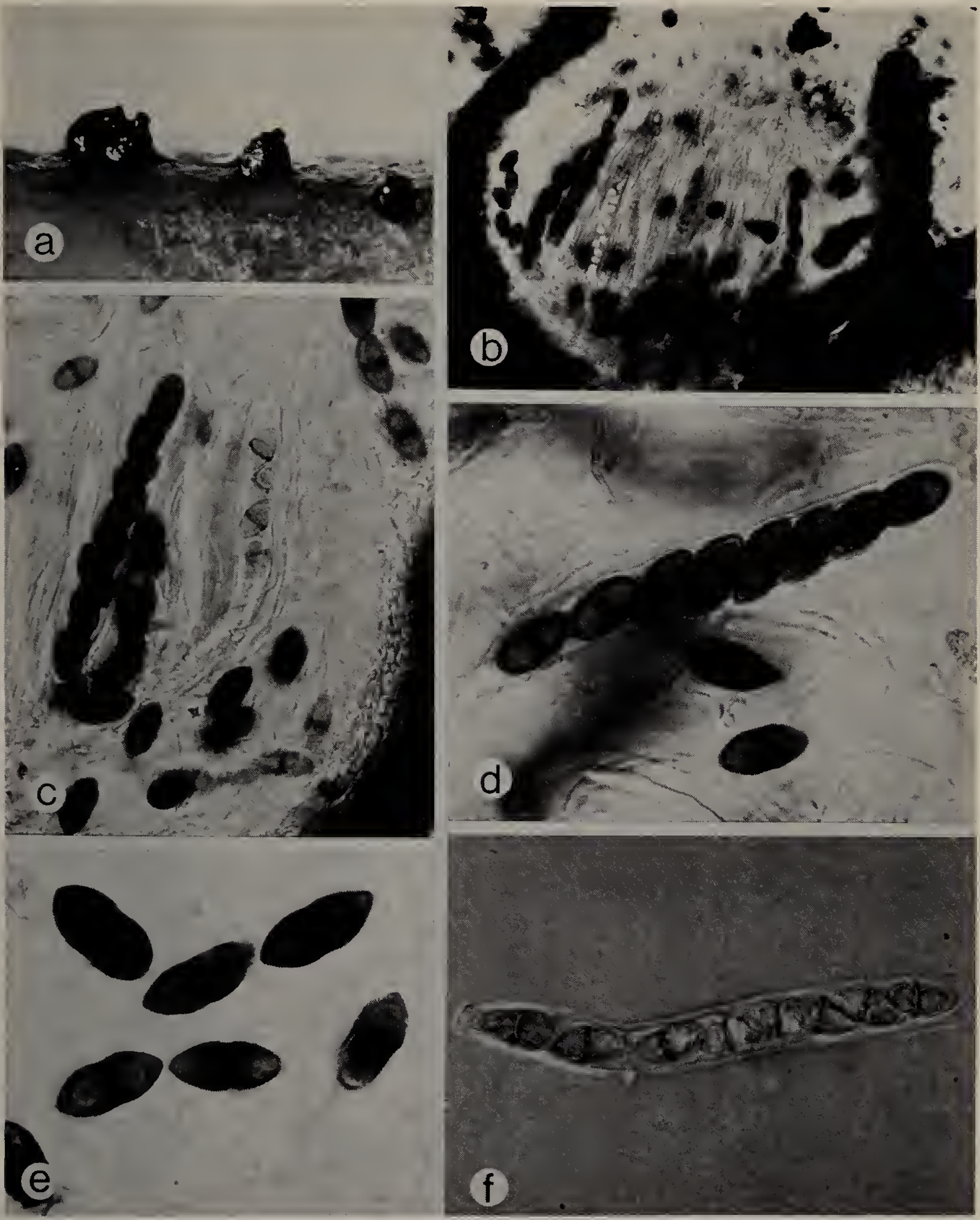

Fig. 1a Ascocarps. (30x).
Fig. 1b Cross section of an ascocarp. (200x).
Fig. 1c Cross section of an ascocarp showing characteristics of the peridium. (450x).
Fig. 1d Ascus containing mature ascospores showing uniseriate arrangement. (700x).
Fig. 1e Spore characteristics. (850x).
Fig. 1f Ascus containing immature ascospores. (700x).

ellipsoidal one-septate in the middle, constricted at the septum, finely echinulate, thick walled, thickenings around the apicies, dark around the septum (Fig. d, e). SUBSTRATE submerged birch blocks. Oct. 10, 1984. Herb. DAOM 193904 (HOLOTYPE).

Etymology: from the Latin, *lignum* = wood and - *maris* = -sea, in reference to the substrate of the species.

Habitat: submerged blocks (b) at site 1.

Deuteromycetes

1. *Cirrenalia macrocephala* (Kohlm.) Meyers et Moore, Am. J. Bot. 47:347, 1960.

Conidia: spirals 19.5-22 µm wide, 18-19.5 µm high; terminal cells 8-12 µm in diameter, 5-10 µm high; basal cells 6.5-8 µm in diameter, 4 µm high.

Habitat: submerged panels (sp, p) at site 1 and (sp) at site 2; blocks (sp, p) at site 1 and (sp) at site 4. This fungus colonized the entire surface of most spruce blocks submerged at sites 1 and 4 and was associated with heavy attack by wood-boring organisms. The only possible report of this fungus in eastern Canada is a symbol on a global distribution map (Hughes 1974). There was no reference to the source of this observation and Hughes could not provide the information (Hughes, pers. com.). We consider this the first report of *C. macrocephala* from the Atlantic Provinces.

2. *Dendryphiella salina* (Sutherland) Pugh et Nicot, Trans. Brit. mycol. Soc. 47:263, 1964.

Conidia: 13-22 x 6.5-8 µm.

Habitat: submerged panels (sp) at site 1; blocks (p) at site 4; intertidal wood at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981).

3. *Humicola alopallonella* Meyers et Moore, Am. J. Bot. 47:346, 1960.

Conidia: apical cell 11.5-13 x 13-18 µm.

Habitat: submerged panels (sp, p, b) at site 1; blocks (p, b) at site 1; intertidal wood at site 5. Previously reported in the Bay of Fundy (Miller & Whitney 1981), Nova Scotia (Boland & Grund 1979) and Nfld. (Hughes 1968). The other Canadian report is from British Columbia (Hughes 1969).

4. *Monodictys pelagica* (Johnson) Jones, Trans. Brit. mycol. Soc. 46:138, 1963.

Conidia: 28.5-39 µm in diameter; 27-36.5 µm long.

Habitat: submerged panels (b) at site 1 and (sp, p, b) at site 2; blocks (b) at site 1; driftwood and intertidal wood at sites 3 and 5. Previously reported in the Bay of Fundy (Miller & Whitney 1981), Nova Scotia (Neish 1970) and Nfld. (Hughes 1968). Other Canadian reports are noted in Booth (1981).

5. *Papulaspora halima* Anastasiou, Nova Hedwegia 6:266, 1963.

Habitat: submerged blocks (b) at site 1. Previously reported in the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Neish 1970). Other Canadian reports noted in Booth (1981).

6. *Trichocladium achrasporum* (Meyers et Moore) Dixon in Shearer et Crane, Mycologia 63:244, 1971.

Conidia: 28.5-31 x 13-18 µm.

Habitat: submerged blocks (b) at site 1. Previously reported in Nfld. (Meyers & Reynolds 1959) as *Culcitalna achraspora*. Other Canadian reports are noted in Booth (1981).

7. *Zalerion varium* Anastasiou, Can. J. Bot. 41:1136, 1963.

Conidia: 21-41.5 x 23-41.5 µm.

Habitat: submerged panels (sp, p) at sites 1, 2 and 4; blocks (p, b) at site 1, (p) at site 4; intertidal wood at sites 3 and 5. This fungus colonized the entire surface at most pine blocks submerged at sites 1 and 4. Previously reported from the Bay of Fundy (Miller & Whitney 1981) and Nova Scotia (Neish 1970). Other Canadian reports noted in Booth (1981).

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Acknowledgements

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Volume 35, pp. 107-108

THIRAM DORMANT SPRAY FOR THE CONTROL OF TAPHRINA COMMUNIS (SADEB) AND ITS RESIDUES IN PLUM FRUIT[1]

Bladder plums or plum pockets, caused by the fungus *Taphrina communis* (Sadeb.) Giesenhagen, is a common disease of European (*Prunus domestica* L.) and Japanese plums (*Prunus salicina* Lindl.) in eastern Canada. The fungus persists on the twigs and bark and host organs are susceptible only when young and tender in the early spring. Plum shoots, flowers, leaves and fruit may all be infected with *T. communis* but the characteristic symptom is swollen and distorted fruit. Two to three weeks after blossoming, small whitish blisters appear on infected fruits. Blisters grow rapidly soon enveloping the whole fruit. At this stage infected plums are elongated, wrinkled, often distorted and almost white. Within a short time they turn brown and drop. Although plum pockets occur in New Zealand on plums it is a different, but closely related fungus species that causes their disease. Our species occurs only in Eastern and Middle North America but produces the same plum pocket symptoms on the fruit as the New Zealand species.

Until recently Bordeaux mixture (8-8-100) applied before bud burst in the spring was the only fungicide available for control of plum pockets. As an orchard fungicide this material has been largely displaced by the more easily handled organic materials. The fungicide thiram (tetramethyl thiuram disulphide) 75 WP at 4.9 kg active ingredient (a.i.)/ha was found to give effective control of *T. communis* and is one of the least phytotoxic materials to foliage and fruit of plums (Gourley 1961). The present study was initiated to obtain information on residues in plum fruit following a dormant season (mid April) application of thiram at the above rate in 3370 liters of water to Burbank plum trees in 3 replicated plots (each consisted of 2 trees) at two locations, Kentville and Wolfville, Kings Co., Nova Scotia. A fourth replicate (2 trees) in each location was kept as check and all replicates were arranged at random in rows. All 16 trees received the recommended summer sprays to control other diseases and insects. In late August, two random samples of ripe fruit (30 each) were collected from each tree at Kentville and Wolfville. Fruit samples were frozen immediately at -10°C and held until residue analysis was made colorimetrically for thiram, using essentially the modified standard carbon disulfide evolution procedure (Keppel 1971). After removing the plum pits the fruit were cut into small portions, mixed, and 100 g were boiled with dilute hot hydrochloric acid and stannous chloride under a reflux condenser. The evolved carbon disulfide was then reacted with ethanolic solution of cupric acetate-diethanolamine. The resultant yellow-complex was measured at 435 nm and thiram residue was calculated from the carbon disulfide found. The practical limit of detectability of the method is 0.05 ppm. Analysis was made on each fruit sample along with fruit samples that received no thiram treatment (check) and fortified fruit check samples at 0.05 ppm thiram.

Satisfactory recoveries of thiram were obtained from fortified check fruit samples (Table I). Table I indicates also that no detectable residues of thiram were found in plum fruit from either location. This study demonstrates that there is no risk of fungicidal residues in the fruit when thiram was applied as a dormant spray to plum trees for the control of plum pocket disease. Thiram is now registered and recommended for control of the above disease in Canada.

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[1] Contribution No. 1690, Agriculture Canada, Research Station, Kentville, Nova Scotia.

Table I Thiram residues in plum fruit.

Location	Check (ppm)[1]	Recovery (%)[2] from fortified check	Thiram (ppm) from treated trees[3]
Kentville	NDR[4]	96.37	NDR[4]
Wolfville	NDR	98.30	NDR

[1] Average of 4 determinations from the check replicate (2 trees).

[2] Average of 4 determinations from the check replicate (2 trees). Fortification level 0.05 ppm thiram.

[3] Average of 12 determinations from the 3 replicates (6 trees).

[4] No detectable residues, 0.05 ppm.

Acknowledgement

The author thanks C. O. Gourley and G. Rudulf for thiram treatments in this study.

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OCCURRENCE OF *CLAVELLODES RUGOSA* (COPEPODA: LERNAEOPODIDAE) ON THE OCEAN POUT, *MACROZOARCES AMERICANUS* IN THE NORTHWEST ATLANTIC OCEAN

Clavellodes rugosa (Kroyer 1837) was first described as *Anchorella rugosa* from the gills of *Anarhichas* sp. in the Northeastern Atlantic. Wilson (1915) recognized the uniqueness of this copepod and erected the new genus *Clavellodes* for it. *Clavellodes rugosa* is a common, widespread parasite of three species of marine wolffishes of the genus *Anarhichas* (*A. denticulatus* Kroyer, 1884; *A. lupus L.* and *A. minor* Olafsen, 1774). It is recorded from all of these hosts in most regions of the North Atlantic Ocean. This note records the occurrence of *C. rugosa* on the gills of the zoarcid eel, *Macrozoarces americanus* (Bloch and Scheider, 1804) collected off the Scotian Shelf. This parasite is previously unreported from this host and locality.

The single host (male, 46.3 cm fork length) was collected October 1983 in a bottom trawl (Western IIA) in 108 m of water at the edge of the continental slope of the Scotian Shelf adjacent to St. Pierres Bank. The host was fixed whole in buffered 10% formalin and later examined in the laboratory. The cephalothorax of two female specimens, and one whole male of *C. rugosa* was dehydrated in 100% ethanol and cleared in methyl salicylate to reveal details of appendage structure. Figures were drawn with the aid of a drawing tube.

Eight adult females of *C. rugosa* (Fig. 1) were recovered from the upper gill arch of the host. Two males were also recovered, each attached to the outside lateral margin of the cephalothorax of a female. Female specimens exhibited the following distinguishing features listed by Wilson (1915): a second antennal exopod armed with numerous small denticles (Fig. 2) and a maxilliped with accessory claw and denticulated inner margin (Fig. 3). We did find a slight variation in the size of the endopod. Kabata (1979) lists the endopod as small (less than 50 μ). Our specimens showed slightly larger endopods of from 70 - 85 μ long. Kabata (1979) records the mandibular dental formula of the male as P2, S1, P1, B3, and notes that some variation could occur in this formula. We found the same dentition in our examination of the mandible of one male.

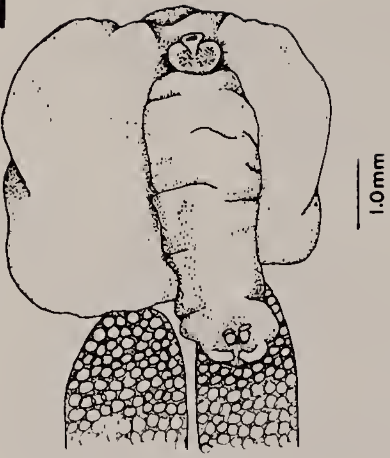
The present find is a new record as it is probably not an accidental infection. Both males and females of *C. rugosa* were found, indicating potential reproduction on the host. The zoarcid eels and anarhichid wolffishes are closely related (Leim & Scott 1966) and occupy similar depth ranges and habitats. Like some other lernaeopodid copepods (ex. *Calvella adunca*) *C. rugosa* may be capable of parasitizing several species of benthic fishes. The paucity of data on parasitic copepods of non-exploited benthic fishes from the Northwest Atlantic is likely responsible for our lack of information on the host-specificity of the parasites. Baird (1850) recorded *C. rugosa* from *Gadus callorius* in the Northeastern Atlantic; this record has been deemed accidental by Scott and Scott (1913) and Kabata (1979). The present record suggests the report of Baird (1850) may be valid.

Specimens of *Calvellodes rugosa* are deposited in the museum of the Canada Department of Fisheries and Oceans, Biological Station, St. Andrews, N.B. E0G 2X0, Catalogue no. 2642-83.

Acknowledgements

We thank Dr. Z. Kabata for information on the structure of the second antennae and maxilliped in the *Lernaeopodidae*, Mr. P.W.G. McMullon for advice on preparation of figures and Debbie Carter for preparing the typescript.

1



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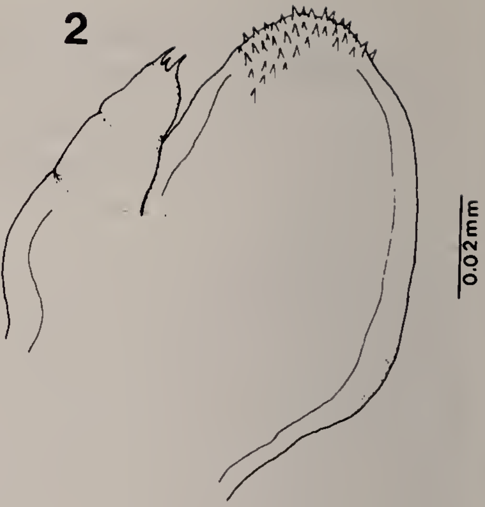

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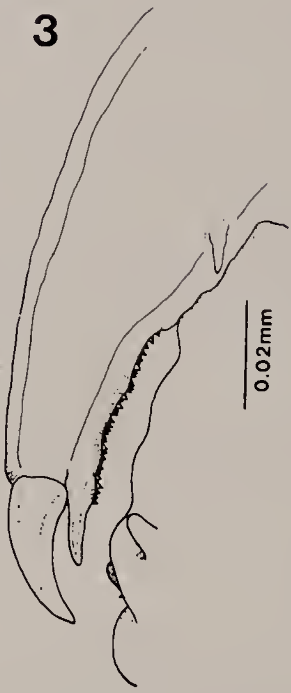

Fig. 1. *Clavellodes rugosa* (Kroyer, 1837), cephalothorax ventral, trunk dorsal (egg sacs partially figured).
Fig. 2. Tip of the second antenna, ventral.
Fig. 3. Detail of the claw of the maxilliped, ventral.

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PROCEEDINGS OF MEETINGS
1984-85
HALIFAX CHAPTER

1st Ordinary Meeting, 1 Oct. 1984
"Annapolis Tidal Power Project: A Renewable Energy Resource." G. Baker, Nova Scotia Tidal Power Corporation.

2nd Ordinary Meeting, 5 Nov., 1984
"Mushrooms of Nova Scotia - Eminent Edibles and Others." C. J. Bird, National Research Council.

3rd Ordinary Meeting, 3 Dec., 1984
"A Magnified Look at the Biology of Silicon." A. Rogerson, National Research Council.

4th Ordinary Meeting, 7 Jan., 1985
"Evening Primrose Oil: A Nova Scotian Success Story." D. Horrobin, Efamol Research Incorporated.

5th Ordinary Meeting, 4 Feb., 1985
"The Potential of Pancreas Transplant in the Treatment of Diabetes." A. MacDonald, Victoria General Hospital.

6th Ordinary Meeting, 4 Mar., 1985
"Environmental Impact of Forest Management Practices in Nova Scotia, Including the Use of Herbicides." W. Freedman, Dalhousie University.

7th Ordinary Meeting, 1 Apr., 1985
"Modern Agricultural Cloning Techniques." G. Hicks, Dalhousie University.

124th Annual General Meeting, 29 Apr., 1985
"Forensic Science." F. T. Tweed, Royal Canadian Mounted Police.

VALLEY CHAPTER

1st Ordinary Meeting, 22 Jan., 1985
"Integrated Pest Management in the Annapolis Valley." R. Rogers, Insect and Mite Monitoring Services.

2nd Ordinary Meeting, 26 Feb., 1985
"Biochemical Control of Apple Softening." A. Dick, Acadia University.

3rd Ordinary Meeting, 30 Apr., 1985
"Maritime Provinces Pre-history." S. Davis, St. Mary's University.

THE PRESIDENT'S REPORT

The Institute, as one of the oldest learned societies in Canada, continues to provide a forum for the discussion of relevant issues in science which impacts upon society.

Seven monthly lectures occurred, with one of the lectures co-hosted with the Canadian Institute of Food Science and Technology. The topics and speakers are summarized: Annapolis Tidal Power Project, Mr. George Baker; Mushrooms of Nova Scotia, Dr. Carolyn Bird; A Magnified Look at the Biology of Silicon, Dr. Andrew Rogerson; Evening Primrose Oil, Dr. David Horrobin; The Potential of Pancreas Transplant in the Treatment of Diabetes, Dr. Allan MacDonald; Environmental Impact of Forest Management Practices in Nova Scotia, Including the Use of Herbicides, Dr. Bill Freedman; Modern Agricultural Cloning Technologies, Dr. Gary Hicks.

Attendance at the monthly meeting was sporadic. I would recommend that the Institute consider increasing the number of lectures co-hosted with other scientific organizations, and include lecture topics dealing with a more general interest theme, as a means of increasing attendance and appealing to a wider cross-section of the community.

Membership in the Institute has shown a small increase this year, but conscientious efforts should be initiated to expand the membership base. A letter and brochure was forwarded to all high school teachers in Halifax, Dartmouth, and the County acquainting them with the monthly topics and speakers and inviting membership in our organization. I would recommend that a teacher be asked to serve as a member of Council on some kind of ongoing basis.

The Institute's publication, The Proceedings, continues to provide our membership with scientific papers with a largely Maritime focus. There is some concern about the increasing costs of journal production under present printing arrangements. Considerable savings may be realized by taking advantage of new developments in computer technology. The matter is under review and we hope that changes can be made in the next year.

I would like to take this opportunity to acknowledge the contribution of Evelyn Campbell, who retired as librarian of the Institute after 48 years of continuous service. She faithfully attended all executive meetings; her perseverance and dedication resulted in the establishment of an extensive catalogue system, including an extensive national and international journal exchange program. The Institute is now involved in a correspondence program that includes 30 institutional members, 12 complimentary Canadian addresses and 19 international addresses, 7 exchanges in Canada, and 206 exchange addresses internationally.

Sylvia Fullerton, assistant librarian at Dalhousie University, has accepted the position as the Institute librarian.

The financial position of the Institute is healthy, thanks to a three-year NSERC grant, and to contributions from the Department of Education and the Nova Scotia university community. Dr. John Walter, our treasurer, deserves special recognition for the many hours he has devoted to ensure the solvency of our operation.

Revenue Canada, Customs and Excise, granted the Institute exemption from federal sales tax on all our publications. The Institute has been registered under the Health Services Act, and excluded in the future from any provincial sales tax levies.

In closing, I would like to thank all members of the executive and Council for their interest and support during my time as president. It has been an honour and privilege to work with such dedicated individuals. May I extend my best wishes to the incoming executive for a most successful year.

Alexander Flack

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1984-85

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